



Review DRAFT – 3/29/13

Nitrogen Mass Balance: Manure, Soil, Crop Removal, and Groundwater at a Grass Field Overlying the Sumas-Blaine Aquifer in Whatcom County

Publication and Contact Information

This report is available on the Department of Ecology's website at <https://fortress.wa.gov/ecy/publications/SummaryPages/13030xx.html>

Data for this project are available at Ecology's Environmental Information Management (EIM) website www.ecy.wa.gov/eim/index.htm. Search User Study ID, bcar0003.

Ecology's Study Tracker Code for this study is 02-039.

For more information contact:

Publications Coordinator
Environmental Assessment Program
P.O. Box 47600, Olympia, WA 98504-7600
Phone: (360) 407-6764

Washington State Department of Ecology - www.ecy.wa.gov

- Headquarters, Olympia (360) 407-6000
- Northwest Regional Office, Bellevue (425) 649-7000
- Southwest Regional Office, Olympia (360) 407-6300
- Central Regional Office, Yakima (509) 575-2490
- Eastern Regional Office, Spokane (509) 329-3400

This report was prepared by a licensed hydrogeologist. A signed and stamped copy of the report is available upon request.

Cover photo:  (Photo by Barbara Carey)

Any use of product or firm names in this publication is for descriptive purposes only and does not imply endorsement by the author or the Department of Ecology.

If you need this document in a format for the visually impaired, call 360-407-6764.

Persons with hearing loss can call 711 for Washington Relay Service.

Persons with a speech disability can call 877-833-6341.

Nitrogen Mass Balance: Manure, Soil, Crop Removal, and Groundwater at a Grass Field Overlying the Sumas-Blaine Aquifer in Whatcom County

by

Barbara M. Carey¹, Lynn VanWieringen², and Joe Harrison³

¹Environmental Assessment Program
Washington State Department of Ecology
Olympia, Washington 98504-7710

²AgHealth Laboratories, Inc.
445 Barnard Blvd.
Sunnyside, Washington 98944

³Livestock Nutrient Management Program
Washington State University
Puyallup, Washington 98371

Waterbody Number: WA-01-1010

This page is purposely left blank

Table of Contents

	<u>Page</u>
List of Figures	v
List of Tables	vi
Abstract	viii
Acknowledgements	ix
Executive Summary	x
Purpose and objectives of the study	xi
Study design	xii
Major findings	xiv
Recommendations	xxiv
Introduction	1
Purpose and objectives	3
Location and setting	6
Soils	8
Hydrogeology	9
Dairy nutrient management plans	11
Local dairy field management	12
Study Design	20
Methods	23
Sampling of nitrogen inputs and related constituents	23
Sampling of nitrogen outputs	24
Sampling of nitrogen residuals	24
Quality assurance	31
Results	34
Nitrogen and chloride inputs	34
Nitrogen outputs	36
Nitrogen residual	36
Soil temperature and soil moisture	37
Soil organic matter and soil chemistry	37
Groundwater	37
Discussion	50
Vadose zone and aquifer properties	50
Groundwater flow	52
Annual nitrogen cycles	52
Groundwater and soil quality	57
Conclusions	73
Factors affecting groundwater nitrate concentration	73
Fall soil nitrate as an estimator of groundwater impacts	74
Estimated nitrate concentrations in leachate	75

Use of the current soil N 55 lb/acre target to protect groundwater.....	75
Implications for other parts of the Sumas Blaine Aquifer	75
Recommendations.....	77
Reduce nitrate loading to groundwater from manure application	77
Monitor to evaluate the effectiveness of management improvements.....	78
References.....	79
Appendices.....	90
Appendix A. Glossary, Acronyms, and Abbreviations.....	91
Appendix B. Drilling Logs for Monitoring Wells	93
Appendix C. List of Analytes Measured in Groundwater, Soil, Manure, Grass, and Irrigation Water.....	102
Appendix D. Manure Sampling Standard Operating Procedures (SOP).	103
Appendix E. Irrigation Water Sampling Standard Operating Procedures (SOP).	105
Appendix F. Grass Sampling Standard Operating Procedures (SOP).	107
Appendix G. Soil Sampling Standard Operating Procedures (SOP).	109
Appendix H. Monitoring Well Construction Information.	111
Appendix I. Equations Used in the Bradbury and Rothschild (1985) Method for Estimating Hydraulic Conductivity.	112
Appendix J. Removed.....	113
Appendix K. Quality Assurance Results	114
Appendix L. Manure Applied.....	136
Appendix M. Irrigation Data.....	138
Appendix N. Grass Crop Results	139
Appendix O. Soil Results.....	146
Appendix P. Grain Size Data from Monitoring Well Soil Samples	148
Appendix Q. Data and Spreadsheet Results for Bradbury and Rothschild (1985) Method Using Specific Capacity for Monitoring Wells on April 4, 2006.....	154
Appendix R. Water level data.....	155
Appendix S. Groundwater Quality Results.....	161
Appendix T. Precipitation, Surplus Water, and Air Temperature Data.....	175

List of Figures

	<u>Page</u>
Figure 1. Study site location within the Abbotsford Sumas Surficial Aquifer.	5
Figure 2. Monthly precipitation at the study site for most dates.	7
Figure 3. Generalized east-west cross-section near the study area.	9

We'll list the rest of the figure titles in the final draft

List of Tables

Page

We'll list the table titles in the final draft

This page is purposely left blank

Abstract

xx

Acknowledgements

The authors thank the following people and organizations for their contribution to this study.

- The dairy producer who generously provided access to their grass field for groundwater, soil, manure and crop sampling. The dairy also provided detailed information on their management practices during the study.
- The Washington Department of Agriculture provided financial support for soil nitrate analyses.
- Chris Clark, Whatcom Conservation District.
- George Boggs, Whatcom Conservation District.
- Nora Mena, Washington Department of Agriculture.
- Deb Davidson, Washington State University.
- Maury Mason and Seth Book, volunteers.
- Washington State Department of Ecology staff:
 - Manchester Environmental Laboratory: Nancy Rosenbower, Dean Momohara, and other analysts.
 - Field Assistants: Tanya Roberts, Sabrina Payne, Bruce Barbour, Mak Kaufman, Tom Buroker, Brian Pickering, Jodi England, Pam Marti, Maggie Bell-McKinnon, Becca Conklin, Bill Kammin, Kelli Slattery, and Kirk Sinclair.
 - Bellingham Field Office: Richard Grout, Andrew Craig, Mak Kaufman, and Doug Allen.
 - Reviewers and advisors: Charles Pitz, Kirk Sinclair, Martha Maggi, and Melanie Redding.
- Former Washington State Department of Ecology staff :
 - Denis Erickson, Darrel Anderson, Devon Reid, Nicoleta Cristea, Ann Butler, Jamison Backous, Sara Livingston, Pam Covey, Andrew Craig, and Bernard Strong.

Executive Summary

Groundwater is a critical natural resource for Washington State, providing a dependable water supply for municipal and domestic consumption, as well as industry, and agriculture. Groundwater is the primary drinking water source for many citizens around the state, particularly those in rural areas.

Contamination of groundwater with nitrate (a common, highly mobile, nitrogen-based chemical compound) is of growing concern in many parts of Washington. Government, community, and agricultural groups around the state have been working to determine the main causes of nitrate contamination in groundwater, and identify cost-effective ways to permanently address the problem. One of the dominant sources of nitrate loading to groundwater in Washington is known to be nitrogen releases from state agricultural practices.

The northwestern portion of Whatcom County is an area of high-intensity agricultural production. The main agricultural businesses in Whatcom County are dairy farming and berry production. Conventional practice for both types of operation is applying large volumes of nitrogen-bearing fertilizer. Whatcom County has the 2nd highest number of dairy cows in the state, and the highest intensity of raspberry cultivation in the country.

Groundwater supply in this area is derived almost exclusively from the Sumas-Blaine Aquifer (SBA), an unconfined aquifer occurring in the unconsolidated glacial deposits that blanket the region (Figure ES-1). Over the last 30 years, this area has been shown to have one of the highest percentages of water supply wells in the state failing to meet the drinking water standard for nitrate (~30% of wells tested show concentrations greater than 10 mg/L as nitrogen). Groundwater is the only source of drinking water for residents living in the northern, rural part of the county. As of 2010, the population in this area was 18,000 to 27,000 people.

Factors that make groundwater in Whatcom County particularly sensitive to water quality impacts from intensive agricultural production include:

- shallow depth to water
- relatively permeable character of the aquifer deposits
- long period of heavy rainfall each year

Combined with the high mobility of nitrate in the environment, these characteristics facilitate rapid transport of nitrate from surface soils to the water table. Recent shifts in the size and number of dairies overlying the SBA have also led to a higher intensity of nutrient loading than in past years.

The study described in this Executive Summary is one of a series of assessments the Washington Department of Ecology (Ecology) has conducted over the past several decades to better characterize the extent and nature of groundwater nitrate conditions in the SBA. Lessons learned from this study will hopefully guide stakeholders and decision-makers in future efforts to restore and protect groundwater resources, both locally and statewide.

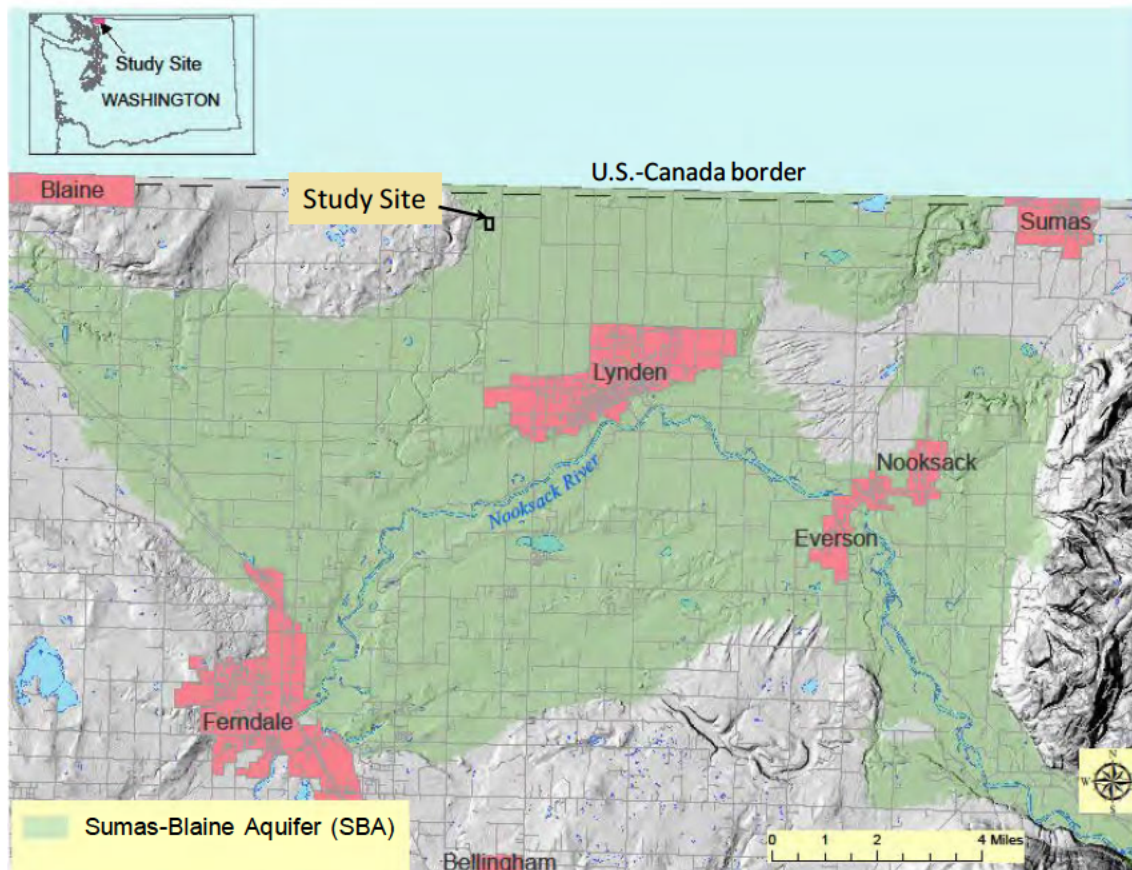


Figure ES-1. Study site location within the Sumas Blaine Aquifer (SBA).

Purpose and objectives of the study

In 2003, the Ecology Bellingham Field Office requested that the Environmental Assessment Program (EAP) conduct a field study to evaluate the effectiveness of Dairy Nutrient Management Plans (Chapter 90.64 RCW) in protecting the quality of the Sumas-Blaine Aquifer. The main objective was to measure and document the sequence of changes in nitrogen at a grass field receiving manure in terms of soil, grass crop, and groundwater over 4 years.

EAP partnered with the Washington State University Livestock Nutrient Management Program (WSU) to design an intensive, multi-media, multi-year monitoring study at a grass field overlying the SBA that received applications of manure. The study approach allowed detailed description of nitrogen transport and fate under conditions unique to this region of the state. Participants from WSU focused on the manure, soil, and crop monitoring aspects of the study, while EAP focused on monitoring and characterizing groundwater conditions underlying the study field.

The technical objectives of the study were to:

- Conduct a long-term, intensive monitoring program at a grass field receiving manure to characterize:
 - Loading of nitrogen to the field
 - Outputs of nitrogen from the field
 - Concentrations of nitrate in groundwater underlying the field
- Compare study monitoring results to guidelines and standards for nitrate, where applicable
- Estimate the amount and concentration of nitrate leaching below the root zone
- Analyze nitrogen cycling to understand where adjustments are possible to increase nitrate uptake and minimize nitrate leaching
- Recommend practices to minimize leaching of nitrate to the underlying aquifer
- Recommend nitrate monitoring strategies

Through this intensive study, we were able to observe the complex interaction of climate, crop, soil, nutrient management practices and aquifer characteristics. Findings from this analysis can be useful for developing strategies to decrease nitrate loading to the underlying SBA so that groundwater can consistently meet the drinking water standard.

Study design

A local dairy producer agreed to allow EAP and WSU to conduct a study at a 22-acre grass field that had received manure over the previous 20 years. The field is located adjacent to the northwestern edge of the SBA (Figure ES-1), where the subsurface deposits are generally finer-grained and less permeable than in the central and eastern parts of the aquifer.

Between the fall of 2004 and the spring of 2009, standard procedures were used to either measure or estimate the major inputs and outputs of nitrogen to the field, including:

- Nitrogen inputs by manure, inorganic fertilizer, and irrigation water applications to the field
- Nitrogen inputs due to atmospheric contributions and in-place chemical conversion of soil organic matter
- Loss (output) of nitrogen via grass harvest, volatilization, and denitrification

These components provided the basis for a detailed mass balance analysis of nitrogen fate at the study field for four growing seasons (Figure ES-2). A mass balance evaluation is equivalent to calculating a nitrogen “budget” for the study field. The difference between nitrogen inputs and outputs provides an estimate of the amount of residual (excess) nitrate that is potentially available to leach downward from topsoil to the water table at the end of each growing season.

Soil and groundwater nitrate conditions were also monitored intensely throughout the study for comparison to the mass balance results, and to examine the environmental response to the varying nutrient management practices and climate conditions observed during the study.

To support the data interpretation, additional field work was conducted to characterize the hydrogeology and soil characteristics of the study site. This included:

- Measuring static water levels in seven dedicated monitoring wells installed at the study field.
- Conducting tests of the hydraulic characteristics of the unconfined aquifer underlying the study field.
- Conducting grain size analyses of site soil deposits.
- Measuring chloride in groundwater to use as a conservative environmental tracer.
- Measuring other constituents in soil and groundwater that contribute to understanding nitrate occurrence and fate.

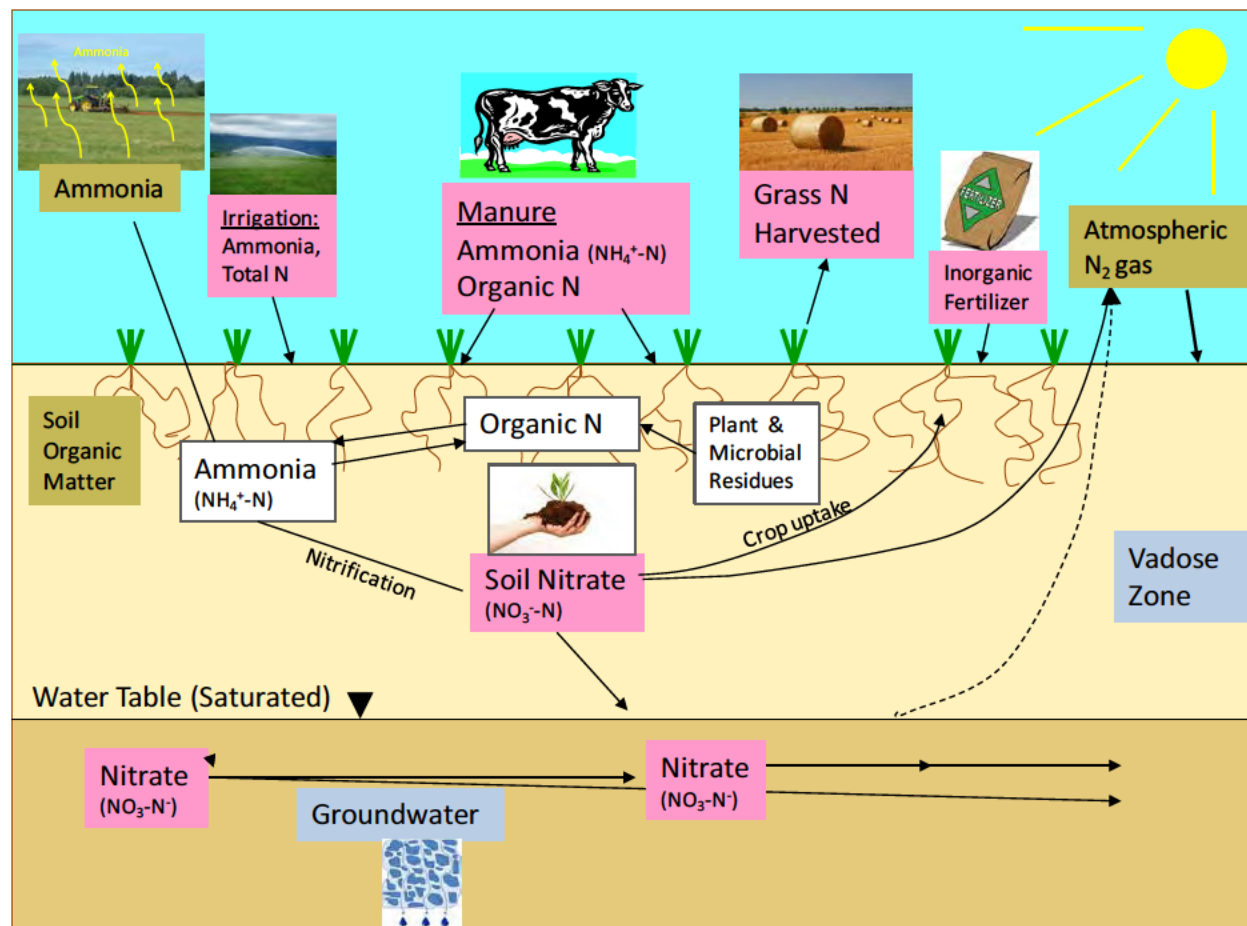


Figure ES-2. Components of a growing-season nitrogen mass balance analysis for the study field.

Media in pink boxes were monitored; items in brown boxes were estimated.

Major findings

Mass balance evaluation results

The mass balance evaluation showed that the large majority of the nitrogen applied to the field during the study was derived from manure (Figure ES-3).

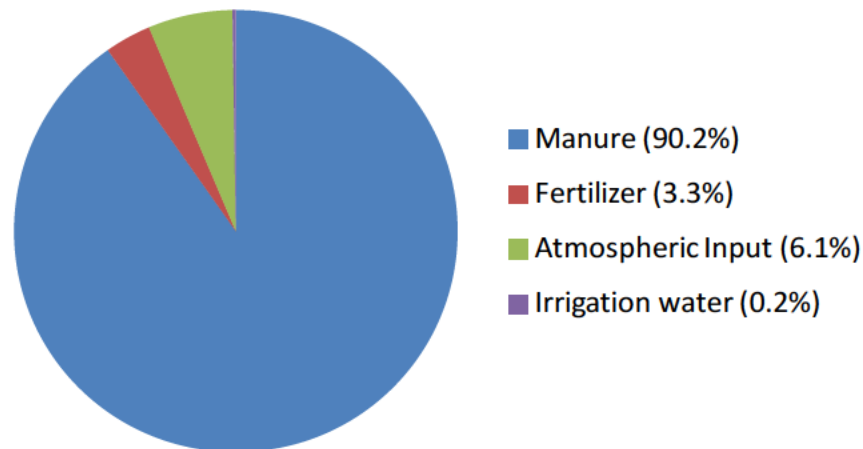


Figure ES-3. Nitrogen inputs to the field by source for 2005 through 2008.

The residual difference between total nitrogen inputs and outputs calculated by the mass balance for each growing season are shown as the blue bars on Figure ES-4. The values are presented in terms of the number of pounds of excess nitrogen (per acre of field) that remained in the top one foot of soil after the final grass harvest. These values provide an approximation of the amount of nitrogen that could reach groundwater if the soil was flushed by water recharging the aquifer in the months following the end of the growing season. For comparison, a line showing 55 lbs/acre has been added to the chart. This value is the end-of-season nutrient management target number that is currently recommended to farmers to optimize crop growth for grass and minimize nutrient loss. The 55 lbs/acre guidance value was not developed for the purpose of protecting groundwater.

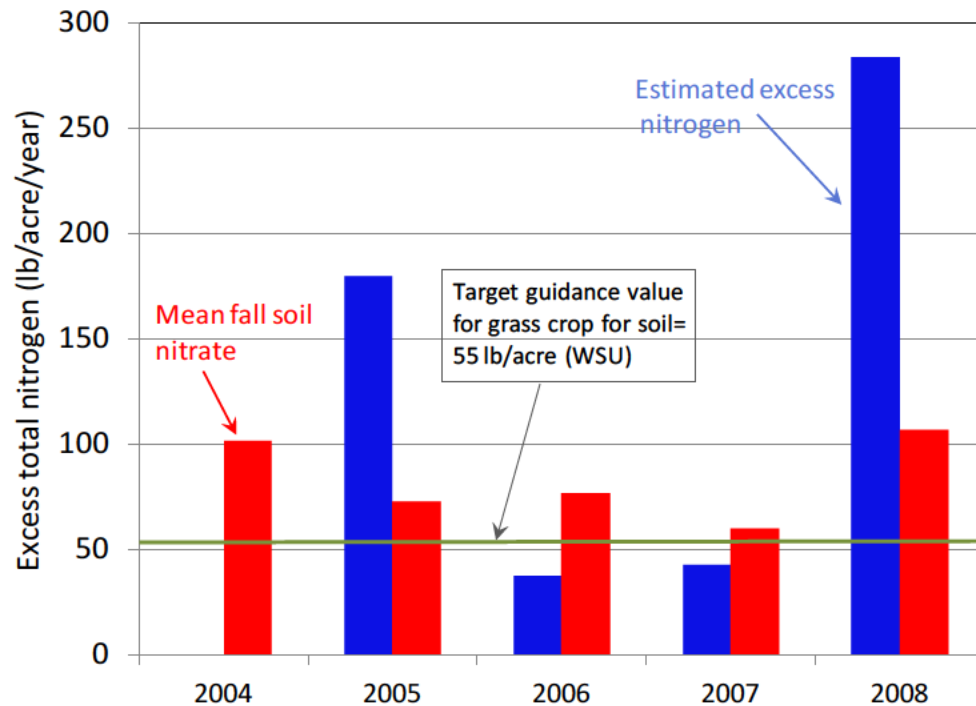


Figure ES-4. Nitrogen residual (excess) at the end of the growing season (lb/acre) estimated by mass balance (blue bars) and fall soil nitrate measurements (red bars).

The figure shows that during two years of the study (2005 and 2008), very large end-of-season excess nitrogen amounts were estimated by the mass balance analysis, suggesting significant risk to underlying groundwater quality. These values were well above the target amount currently recommended to producers. Smaller residual nitrogen values, below the target value, were estimated for 2006 and 2007. No mass balance residual value was calculated for 2004.

Soil nitrate sampling results

An alternative, although less accurate, way of estimating the amount of residual nitrogen in a farm field relies on measurements of shallow soil-nitrate concentrations collected in the fall. This technique (which was developed primarily to optimize crop output) is commonly used by farmers to manage nutrient conditions in their fields, and it has become an informal, low-cost measure of risk to groundwater.

Figure ES-4 shows the average fall (September through October) soil nitrate concentration that was measured in the study field each year, converted to a pounds-per-acre value (green bars), allowing direct comparison to the mass balance results.

The nitrogen excess amounts predicted by the fall soil nitrate method show less variation than the mass balance estimates throughout the study period. The soil nitrate method significantly underestimated the nitrogen excess for the 2005 and 2008 years in comparison to the mass

balance approach. This means the soil nitrate results significantly underestimated the risk to groundwater for these years. In all cases the soil-nitrate-derived excess values were at or above the 55 lb/acre target criteria.

Groundwater sampling results

Intensive monitoring showed that, under the weather and nutrient management conditions observed during the study, shallow groundwater nitrate concentrations beneath the field were often greater than the drinking water health standard of 10 mg/L-N. Despite evidence that a portion of the nitrate that reached groundwater was lost due to denitrification, 65 % of 308 shallow groundwater nitrate results were above 10 mg/L-N, with the highest concentration at 45 mg/L-N.

Figure ES-5 illustrates the groundwater nitrate concentrations observed over time in the 6 shallow groundwater monitoring wells installed for the study. Nitrate concentrations were initially well above the groundwater quality standard in 2004 and gradually declined through the summer of 2008. At the end of the growing season in 2008, nitrate concentrations began to increase again, rising above the drinking water criteria in 4 out of the 6 wells.

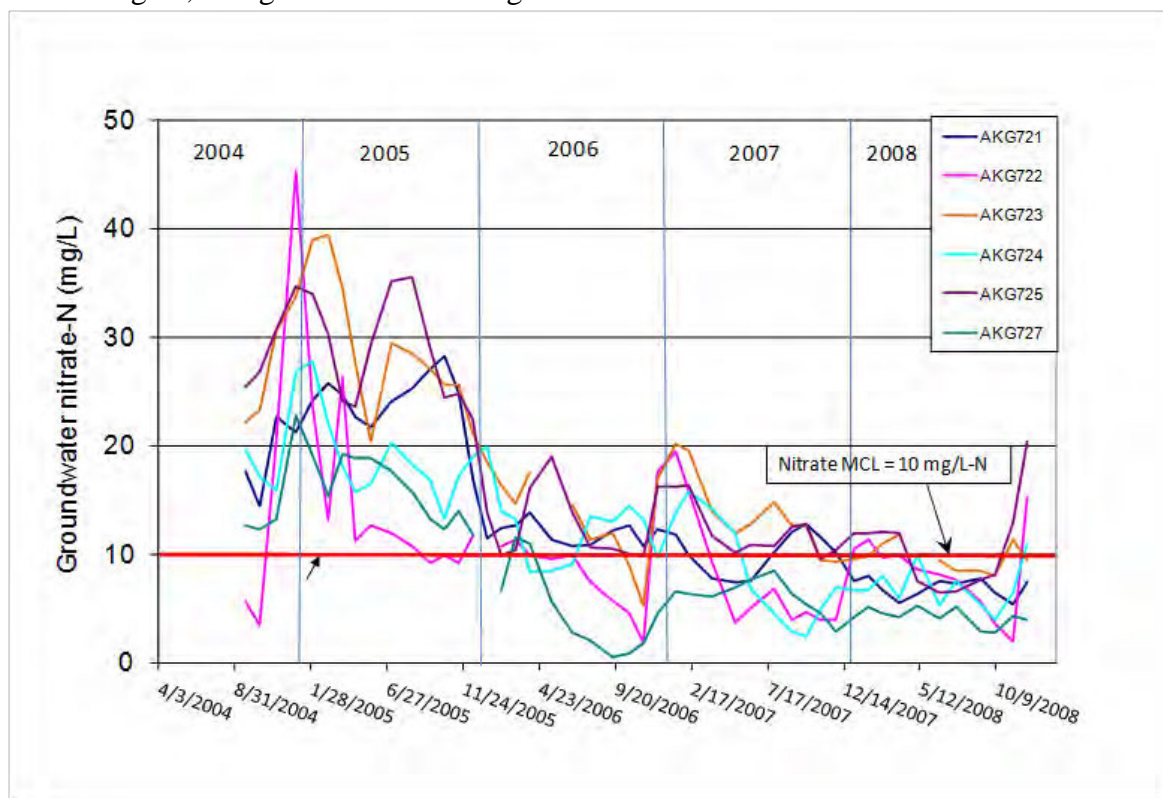


Figure ES-5. Shallow groundwater nitrate-N concentrations. (...Final report

Figure ES-6 shows the average winter groundwater nitrate concentration (right hand axis) in comparison to the end-of-season nitrogen residual values estimated for each year of the study (left hand axis). Winter groundwater concentrations are presented to highlight how the aquifer responded as fall recharge infiltrated through the soil column and flushed the excess nitrate remaining at the end of each growing season.

The figure indicates that the mass balance method of calculating the end-of-season nitrogen residual is a better predictor of the overall groundwater concentration pattern. The steady decline in the groundwater concentration between 2004 and 2007 parallels a significant improvement in the balance between study field nitrogen inputs and outputs. When the nitrogen budget returned to a large end-of-season excess in 2008, the underlying groundwater concentrations quickly began to increase again. The soil nitrate-derived excess values do not show a reliable correlation to the groundwater condition. It is notable that although the nitrogen excess amount calculated by the mass balance analysis was below the 55 lb/acre target guidance value, groundwater nitrate concentrations, on average, remained above (did not meet) the drinking water standard.

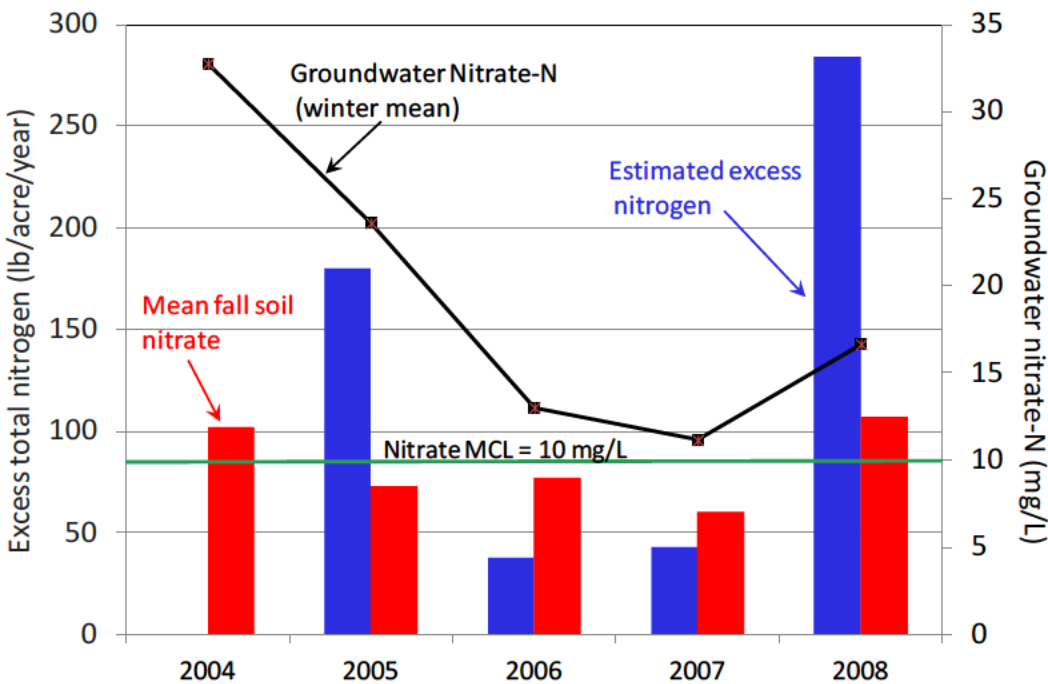


Figure ES-6. Average winter groundwater nitrate concentrations (black line) compared to two fall nitrogen residual estimates (1) excess nitrogen –blue bars; (2) mean fall soil nitrate (red bars).

Factors affecting groundwater nitrate concentrations

The data collected during the study showed that groundwater conditions underlying the grass field on any given day of the study period were the result of a complex interaction between many different factors, including:

Nitrogen application rate

The balance between the amount of nitrogen applied to the field and the amount of nitrogen removed by harvest was an overriding factor affecting groundwater nitrate concentrations. During the study, groundwater concentrations tended to be higher in years with a large residual excess N value; concentrations were lower when the N application rate was in closer balance

with the rate of crop removal. This indicates that, to minimize the impact to groundwater quality, manure applications need to be precisely tuned to the crop demand.

Timing of manure applications

The likelihood of loss of soil nitrate to underlying groundwater is highly sensitive to the timing of manure application. If manure is applied to a field during a period of the year when crop growth rates are declining or dormant, and recharge is increasing, excess nitrate is prone to leach downward. This was evident during the study, when application of manure past the end of the typical growing season resulted in a corresponding rise in underlying groundwater nitrate concentration.

Likewise manure applications in late winter/early spring (January through March) may add to recently mineralized nitrate and lead to significant transport to groundwater. We saw indications of nitrate leaching to groundwater during January and February in two years but not manure-associated chloride, indicating a source other than the previous year's manure. The most likely source of this late winter nitrate is from soil organic matter that is bacterially converted to ammonium and then nitrate. This indicates that the application of manure during the months when precipitation exceeds evapotranspiration (October through March) presents a high risk for nitrate leaching to groundwater.

Recharge

The amount of recharge that infiltrates the soil column during the months following the final crop harvest can have a significant effect on the amount of nitrate leaching to the water table. This is because recharge serves as the primary transport mechanism for nitrate stored in soils at the end of the growing season. The larger the volume of recharge moves through the root zone, the more excess nitrate stored in the soil will be transferred to the dissolved phase and carried rapidly to the water table. This process can be compounded by a corresponding rise in the water table (also driven by recharge). This shortens nitrate transport distances and times. In combination with an overall decline in nitrogen loading between 2005 and 2007, the decrease in the amount of fall recharge that infiltrated through the soil column (due to climate variability) was probably a contributing factor in the steady decline in groundwater nitrate concentration (Figure ES-7).

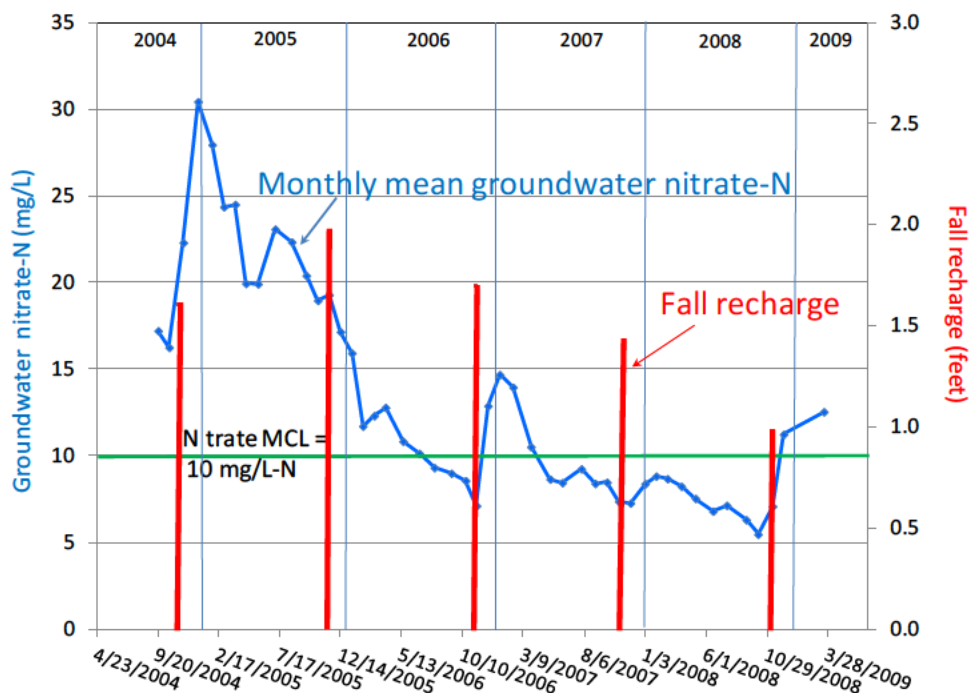


Figure ES-7. Annual fall recharge and groundwater nitrate concentrations.

Tillage

Tillage in the spring before the study began appears to have initially caused a sizable release of nitrate from mineralized soil organic matter. Nitrate-N concentrations in groundwater the winter after tillage were as high as 45 mg/L-N. The nitrate concentration in groundwater decreased over the next 3 years of the study, suggesting the effect of the tillage on the groundwater nitrate condition declined through the remainder of the study period.

Temperature and Soil Moisture

The ability of the crop to uptake and remove nitrogen (an ‘output’ component of the nitrogen budget) was affected by both temperature and soil moisture.

Warmer growing season temperatures during 2005 to 2007 resulted in higher crop uptake of nitrogen than during the comparatively cooler season of 2008. The highest year for thermal input to the grass crop was 2007 and coincided with the highest crop nitrogen removal. These conditions resulted in significantly smaller mass balance nitrogen excesses at the end of the 2006 and 2007 growing seasons. Lower crop uptake in 2008 resulted in an elevated mass balance nitrogen excess and corresponding increases in groundwater nitrate concentrations.

The degree of moisture in soil can have a controlling effect on the rate that soil nitrogen is converted to a chemical form (ammonium) that is suitable for crop uptake. When soil moisture values declined below a key level in 2005 and 2006, this conversion slowed significantly, resulting in lower crop uptake of nitrogen. Irrigation earlier in the third year increased soil moisture and prevented the crop from going dormant and allowed greater nitrogen uptake.

Denitrification

If the proper conditions are present, conversion of nitrate to nitrogen gas by microbes in the subsurface can help to reduce the concentration of nitrate in groundwater. During the study, 4 out of 6 of the shallow monitoring wells exhibited periodic low dissolved oxygen conditions favorable to denitrification. Denitrification probably muted the effects of excess nitrogen in the groundwater sampled from these wells. This suggests that impacts on groundwater nitrate conditions will probably be more pronounced in areas where groundwater dissolved oxygen concentrations are high and denitrification rates are low.

Fall soil nitrate as an estimator of groundwater impacts

Fall soil nitrate tests may help dairy producers evaluate the appropriate nutrient balance for optimizing crop growth. However, shallow soil nitrate sampling is not a reliable tool for accurately predicting groundwater impacts. One reason for this is the wide variability in concentration that can be observed in soil nitrate sampling results, depending on the particular timing of the sampling (Figure ES-8). Timing of manure applications and precipitation events, along with the associated downward movement of nitrate below the sampling horizon, play a significant role in this variability. This variability is one reason why reliance on fall soil nitrate measurement results can lead to significant underestimates of the true risk posed to groundwater quality.

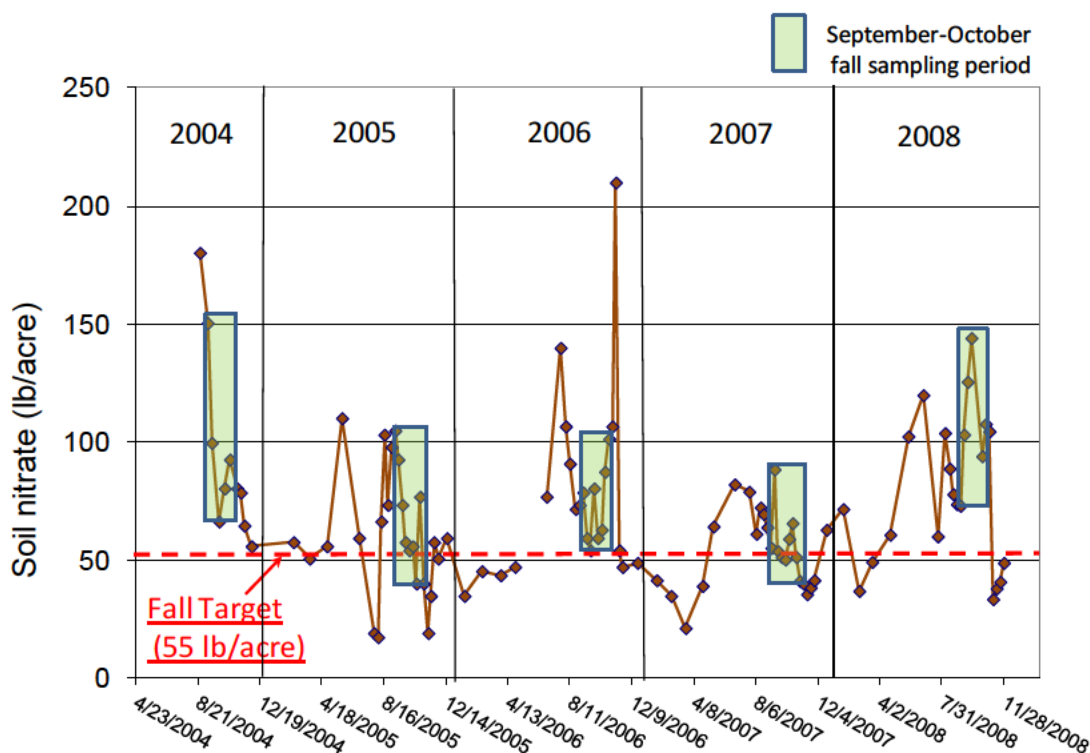


Figure ES-8. Soil nitrate concentrations.

Each measurement is the mean of duplicate composite samples.

Winter mineralization and early spring manure applications

Although bacterial conversion of soil organic nitrogen to nitrate slows in the winter, groundwater nitrate and chloride concentrations in early 2005 and 2008 indicated an increase in nitrate concentration unrelated to the previous season's manure application. A likely source, in addition to residual from tillage in 2005, is newly mineralized nitrate from soil organic matter. Soil nitrate concentrations of 58 and 72 lb/acre in February 2005 and January 2008, combined with high precipitation and a high water table each year, appears to have moved the newly mineralized organic nitrogen into the groundwater.

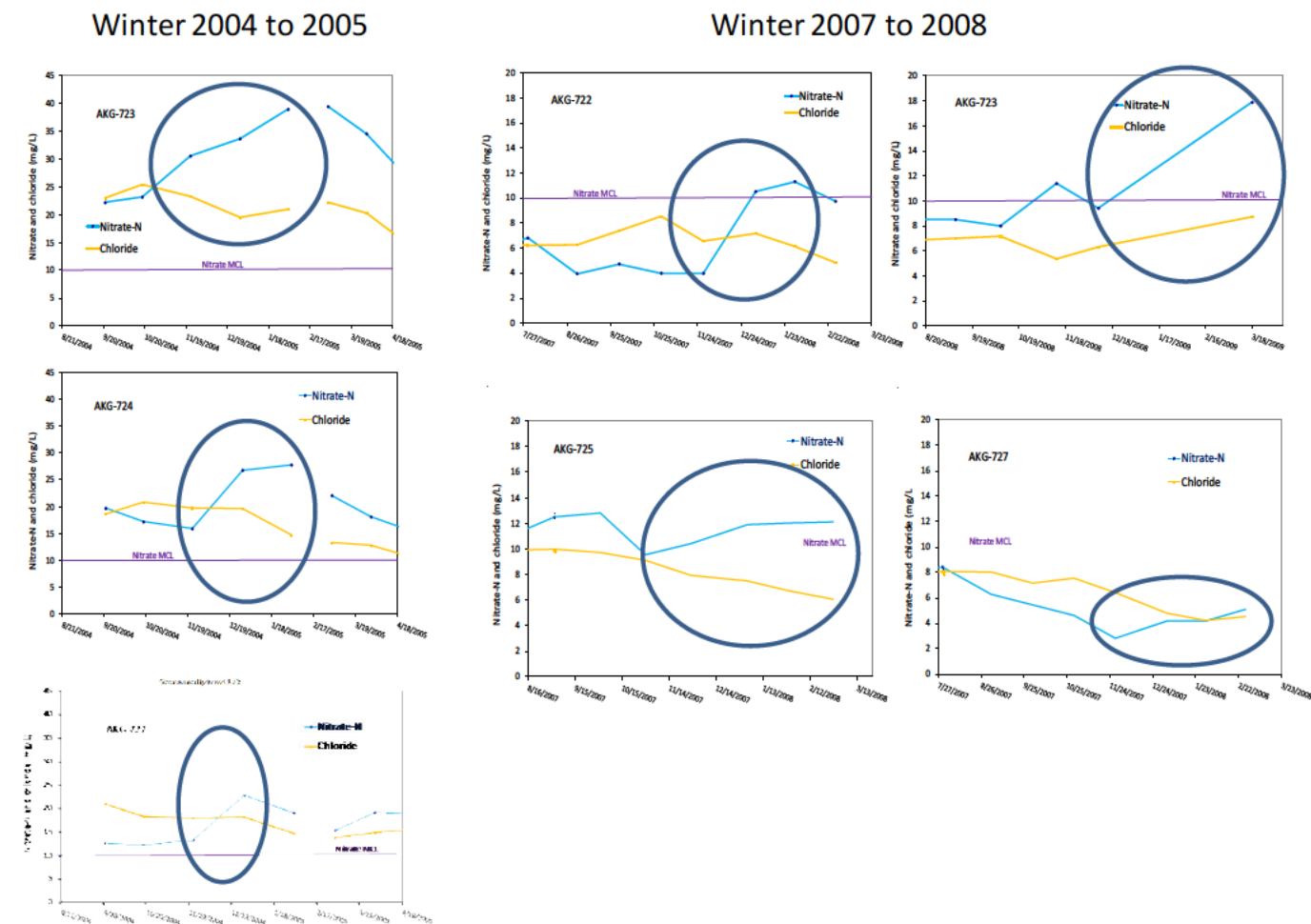


Figure ES-9. Comparison of nitrate and chloride concentrations in shallow groundwater in the winter of 2004 to 2005 and 2007 to 2008.

Using mass balance or fall soil nitrate estimates of nitrogen excess to predict leachate concentrations

The study examined the value of using different estimates of excess nitrogen to predict the concentration of nitrate in leachate infiltrating to the water table with fall recharge. If the estimates of leachate concentration reliably correlate to underlying groundwater conditions, this could provide farmers an alternative to direct groundwater monitoring.

Leachate concentration estimates were developed by combining end-of-season estimates of excess nitrate mass in the soil column with the subsequent fall recharge water volume. Figure ES-10 illustrates the results of this analysis, comparing the predicted leachate nitrate concentrations to the actual winter-time groundwater concentrations measured below the study field. Neither method of predicting the leachate concentration produced values that reliably matched the measured groundwater condition, underestimating the true condition half the time.

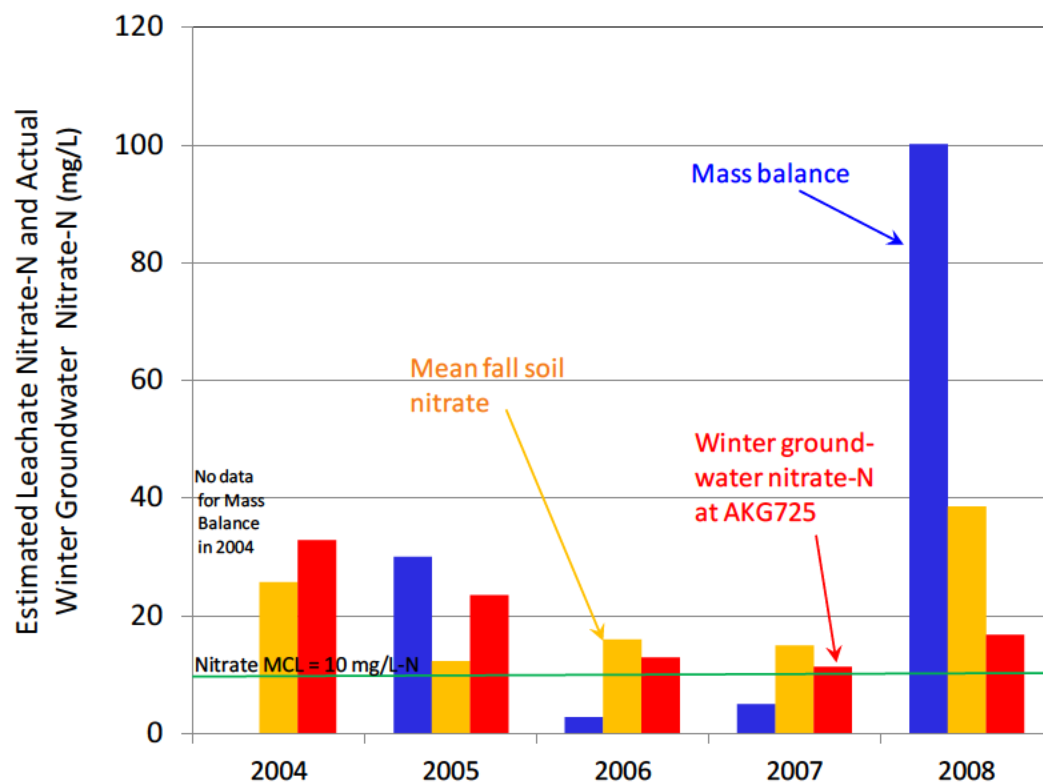


Figure ES-10. Comparison of predicted leachate nitrate concentration using 2 methods. (Mass balance-blue; Mean fall soil nitrate-gold) to the mean measured winter groundwater nitrate concentration (red).

The interactions described above are very complex. Factors include attenuation reactions, timing and amount of recharge, variation in crop uptake due to weather and irrigation, concentration of groundwater mixing with the leachate, ongoing generation of soil nitrate pass the end of the growing season. Therefore, estimates of the leachate concentration were a generally poor predictor of nitrate conditions actually observed at the water table. This is another indication that

using estimates of excess nitrate in the soil at the end of the growing season is an unreliable substitute for direct groundwater monitoring.

Use of current soil nitrate 55 lb/acre target to protect groundwater

Current Washington State University (WSU) guidance for manured grass fields in western Washington recommends an optimum value of 55 lbs/acre of nitrogen or less in soils at the end of the growing season. If the field meets this value, no changes in nutrient management are needed the following spring. This recommendation, however, was not developed to take groundwater impacts into account and may consistently result in end-of-season soil nitrate conditions that still pose a significant risk to groundwater.

During the study the range of maximum fall soil nitrate values was 89 to 210 lb/acre, or 1.7 to 3.8 times higher than the fall soil nitrate target for nutrient balance in western Washington (55 lb/acre). The maximum fall soil nitrate concentration is a better gauge of the amount of nitrogen potentially available for leaching than the amount immediately after harvest as prescribed in the WSU guidance.

The calculated leachate nitrate-N concentration that would result from combining the fall soil nitrate threshold concentration for grass (55 lb/acre) with the annual volume of fall recharge observed ranged from 10 to 21 mg/L during the study. This suggests that the 55 lb/acre guidance value will consistently result in infiltrating leachate that will have a nitrate concentration above the groundwater quality standard.

These points suggest that the post-harvest soil nitrate guidance for the amount of soil nitrate considered acceptable needs to be reviewed and revised to take groundwater impacts into account.

Implications for other parts of the Sumas Blaine Aquifer

Grain size analyses and hydraulic testing of the shallow aquifer suggest that the study site is generally finer-grained than most of the SBA. The finer-grained character of the deposits underlying the study field results in slower groundwater transport velocities and lower dissolved oxygen concentrations. These conditions are more favorable to the reduction of nitrate in groundwater by denitrification.

Loss of nitrate via denitrification in the site subsurface was probably greater than would be expected in coarse-grained areas, where dissolved oxygen concentrations are too high for denitrification to occur. Nitrate impacts to groundwater from manure management practices similar to those monitored in this study would probably be more severe in areas of the aquifer with high dissolved oxygen.

Increasing precipitation from west to east over the SBA results in higher recharge to groundwater from west to east. Increasing recharge can hasten nitrate movement below the root zone, increasing the load of nitrate to groundwater.

These points suggest that the results observed during the study do not represent a worst case scenario for the SBA for the impact of manure application practices on underlying groundwater.

Recommendations

Reversing groundwater contamination in the SBA will require two major actions: (1) Reducing nitrate loading to groundwater and (2) monitoring to evaluate the effectiveness of measures to reduce nitrate loading. The following actions are suggested to improve groundwater quality.

Reduce nitrate loading to groundwater

Develop a process to ensure that manure and fertilizer nitrogen inputs and outputs are tracked on a field-by-field basis and used to prevent water leaching below the root zone from degrading groundwater. Involvement of state and local organizations in partnership with universities is needed to help farmers improve nitrogen use efficiency.

Some of the lessons learned in this study to decrease nitrate leaching to groundwater in the SBA include:

1. Pay close attention to the timing of nitrogen application. Schedule the last manure application to occur by mid-September. Manure should not be applied during months with a significant water surplus and low soil temperatures (October through mid-March).
2. Where groundwater is well-oxygenated and denitrification rates are low, take special care to apply manure at the proper times and amounts.
3. Minimize use of inorganic fertilizer on manured fields. If soil moisture is low, consider irrigating in the summer to increase mineralization and nitrification as an alternative to increase available nitrate to the crop.
4. Extend the time between tillage events in order to decrease the amount of nitrogen reaching groundwater.
5. Avoid applying manure to forage crops during the first season following tillage.
6. In fields similar to the study field, where nitrate mineralization appeared to occur during the winter, avoid manure application early in the year when surplus water is high and crop uptake of nitrogen is low (January/February).
7. Improve soil nitrate sampling by taking multiple samples after the last in each manured field (assuming that the last manure application is made by mid-September) and collecting spring soil nitrate samples before the first application of the year. Fall and spring soil sampling results should be used to determine the appropriate amount and timing of future manure application. (Remember the high variability of soil nitrate results and the potential for leaching before samples are collected.)
8. Encourage cultivation of grass and perennial crops that can take up significantly more nitrogen than corn.
9. Where irrigation water is available, apply as needed based on field soil moisture data to promote maximum nitrogen uptake and removal during the growing season.

10. Track off-site manure transport and application and ensure that application is included in target field's nutrient management plan.
11. Compare results from this study with results of the current Whatcom Conservation District's Application Risk Management System study.

Monitor to evaluate the effectiveness of management improvements

There is no substitute for groundwater monitoring for evaluating either the amount or the concentration of nitrate that actually reaches the water table. However, on-farm mass balance analyses could serve as a screening tool to focus closer inspection of groundwater

temporarily leave this line here – for section break

Introduction

The Sumas-Blaine Aquifer (SBA) underlies about 150 square miles and is the exclusive source of drinking water for over 18,000 to 27,000 of northwest Whatcom County, Washington (U.S. Census, 2010). The SBA is part of the larger Abbotsford-Sumas Aquifer that straddles the U.S.-Canada border. The aquifer averages ~50 feet in thickness in the U.S. (Figure 1; Tooley and Erickson, 1996).

Groundwater within the SBA flows predominantly from north to south (Canada to the U.S.) but local patterns of flow are also affected by interactions with surface water features (Figure 1). The depth to water is less than 10 feet in most of the SBA, but is more variable on the British Columbia side. In winter the depth to water is near the surface in much of the SBA, requiring artificial drainage to prevent flooding due to heavy precipitation.

Intensive agriculture has been conducted over the shallow SBA for the past 50 years. Dairy farming has historically been the predominant agricultural activity over the SBA, with raspberry and other berry production becoming more prominent in the past 20 years. Currently there are approximately 37,000 acres in dairy production in Whatcom County, 8,200 acres of raspberries and 2,600 acres of blueberries (Embertson, 2010; Whatcom Farm Friends, 2012).

Berry and poultry production have replaced most of the dairy land in the Abbotsford area of British Columbia north of the Canada border. Zebarth et al (1998) showed that much of the surplus nitrogen that leaches to groundwater or runs off to surface water on the Canadian side of the aquifer is due to changes in agricultural practices over the past 40 years. Small fruit crops, which have replaced almost all of the cropland formerly in grass for dairy cows, take up only 10% of the amount of nitrogen taken up by forage crops, leaving more nitrogen available for infiltration below the root zone (Zebarth et al, 1998). Currently there are about 2,500 acres in raspberries and 1,000 acres in blueberries over the Canadian portion of the aquifer (Sweeney, 2012).

Nitrate concentrations in excess of the maximum contaminant level (MCL) acceptable in public drinking water supplies (10 mg/L-N:Chapter 246-290-310 WAC) have been documented in the SBA for at least the past 23 years (Erickson and Norton, 1990; Garland and Erickson, 1994; Cox and Kahle, 1999; Erickson, 2000 and 1998; Carey, 2002; Almasri and Kaluarachchi, 2004; Mitchell et al, 2005; and Redding, 2008).

In 1997, 21% of 250 private wells tested in the SBA exceeded the drinking water limit (Erickson, 1998). In a 35-well subset of the 250 wells previously sampled, 71% contained nitrate-N at concentrations greater than 10 mg/L between 2003 to 2005 (Redding, 2008).

Several public water supply wells near the City of Lynden exceed the drinking water standard for nitrate affecting over 1,000 residents (Pell, 2011).

High nitrate concentrations in drinking water can cause methemoglobinemia, or blue-baby syndrome, in infants. This potentially life-threatening condition is caused by nitrate converting to nitrite in the digestive system. The nitrite then reacts with iron in hemoglobin, restricting

transport of oxygen to the cells. An increased risk of spontaneous abortion or certain birth defects may be associated with drinking nitrate-contaminated water. Cancer risks have also been associated with elevated nitrate in water and food (Centers for Disease Control and Prevention, 1996; Chiu and Tsai, 2007; Ward et al, 2005; Weyer et al, 2001; Jasa et al, 1999; Rademaher et al, 1992).

Besides human health effects of nitrate, groundwater nitrate can also adversely affect surface water by increasing primary productivity in streams, rivers, and lakes hydraulically connected to the aquifer system. When algal and plant material that depend on nitrogen decompose, oxygen depletion can affect fish and other aquatic life (Matson et al, 1997; Howarth and Marino, 2006).

On the Washington side of the aquifer, the number of dairy farms has dropped by one-half in the past decade. However the number of milk cows has only decreased by 30% (Embertson, 2010). Because dairy waste is now applied on a smaller area, nutrient loading has intensified on the remaining land. Fields formerly planted in grass to feed dairy cows are being converted to crops that take up less nitrogen and as a result, contribute a surplus of nitrogen similar to that on the Canadian side of the aquifer.

Agricultural activities overlying the Canadian portion of the aquifer system have also resulted in groundwater quality impacts (McArthur and Allen, 2005). The concentration of nitrate along the Canada-U.S. border area are variable with the highest concentrations on the eastern side of the aquifer.

Although we don't know the concentration of nitrate in groundwater entering the U.S. from the Canadian side of the aquifer system, groundwater typically flows horizontally in the direction of flow (generally north to south in the SBA) with solute concentrations dispersing deeper into the aquifer with distance from the source. Therefore shallow groundwater in the U.S. would most likely not be affected by activities north of the border.

Since the Dairy Nutrient Management Act was adopted in 1998 (Chapter 90.64 RCW), much effort has gone into developing nutrient management plans for dairies in the area. Yet questions remain about the best management practices necessary to simultaneously maintain crop health and reduce and prevent nitrate contamination in local groundwater. Because the SBA already displays a high vulnerability to nitrate leaching (Erwin and Tesoriero, 1997) and so much of the land overlying the aquifer receives dairy nutrients in the form of liquid manure, it is important to optimize nutrient management. Some of the issues of concern for land application of manure include:

- Rate of nitrogen application
- Timing of manure application
- Soil type (organic matter influence on N and denitrification)
- Methods for estimating surplus nitrogen (soil nitrate, leachate nitrate concentration)

While one goal of manure application is to apply an amount of nitrogen that will contribute to optimal crop growth, achieving a close balance between inputs and outputs of nitrogen to protect groundwater quality is often elusive.

A number of studies have shown that measured concentrations of nitrate in soil or soil pore-water, or estimates of surplus nitrogen loading from mass balance surveys, are not reliable predictors of underlying groundwater nitrate concentrations (Viers et al, 2012; van der Schans et al, 2009; van Es et al, 2006; Basso et al, 2005; Zebarth et al, 1998; Bechmann et al, 1998). These methods can either overestimate or underestimate groundwater impacts. This is because transformations between various forms of inorganic and organic nitrogen are difficult to predict. However, Goss et al (1995) found that although farm nitrogen budgets did not accurately predict groundwater nitrate concentrations, they were useful for identifying farms likely to cause environmental contamination.

The timing and amount of manure applied to crops are the key factors in maintaining nitrogen balance on manured fields (Oenema et al, 2010; Van Es et al, 2006; Verloop et al, 2006; Di and Cameron, 2002).

The amount and timing of precipitation that carries soil nitrate to the water table also plays a significant role in the concentration of nitrate ultimately reaching the water table (Sonneveld et al, 2010; Oenema et al, 2010; de Ruijter et al, 2007; Boumans et al., 2005; Zebarth, 1998). Because heavy rainfall in winter months leaches soluble nitrate below the root zone, Smith et al (2002) suggest that liquid manure applications not be made during wet winter months in Nitrate Vulnerable Zones of the UK.

Purpose and objectives

The Ecology Bellingham Field Office of the Water Quality Program requested that the Environmental Assessment Program (EAP) design and conduct a long-term study at a dairy farm to evaluate the effectiveness of Dairy Nutrient Management Plans (DNMP's) in protecting the quality of the SBA. DNMP's were established under the 1998 Dairy Nutrient Management Act (Chapter 90.64 RCW). Because this was a multi-year study, variation in weather, manure application, and crop age could be taken into account.

EAP partnered with the Washington State University's Livestock Nutrient Management Program (WSU) to design a multi-media sampling program at a typical manured grass field. This study approach allowed us to track nitrogen transport and fate under conditions unique to the SBA.

The objectives of the study were to:

- Conduct a long-term, intensive monitoring program at a grass field over the SBA to characterize: loading of nitrogen to the field, outputs of nitrogen from the field, and concentrations of nitrate in groundwater underlying the field.
- Compare study monitoring results to guidelines and standards for nitrate where applicable
- Estimate the amount and concentration of nitrate leaching below the root zone
- Analyze nitrogen cycling to understand where adjustments are possible to increase nitrate uptake and minimize nitrate leaching
- Recommend practices to minimize leaching of nitrate to the underlying aquifer
- Recommend nitrate monitoring strategies

Prior to the study, key areas that were not well understood include:

- How much variability occurs in soil nitrate results during the fall and early winter?
- How does the annual application of total nitrogen compare to the mass of nitrogen removed in the grass crop? Can a grass crop take up more nitrogen than applied, i.e., can mineralization of residual organic nitrogen provide significant crop nutrition?
- What is the lag time between nitrogen application, and the arrival of nitrate-enriched leachate at the water table?
- How are nitrogen cycle transformations affected by climate/weather and management practices?
- Can fall soil nitrate data collected to evaluate nutrient balance serve as an indicator of leaching to groundwater?

To help answer these questions, the study uses results from the following areas:

- Intensive soil and groundwater monitoring
- Measurement of nitrogen inputs (manure and fertilizer)
- Measurement of N uptake by crop removal
- Estimates of processes not monitored (volatilization, denitrification, leaching)
- Measurement of groundwater elevations
- Weather monitoring

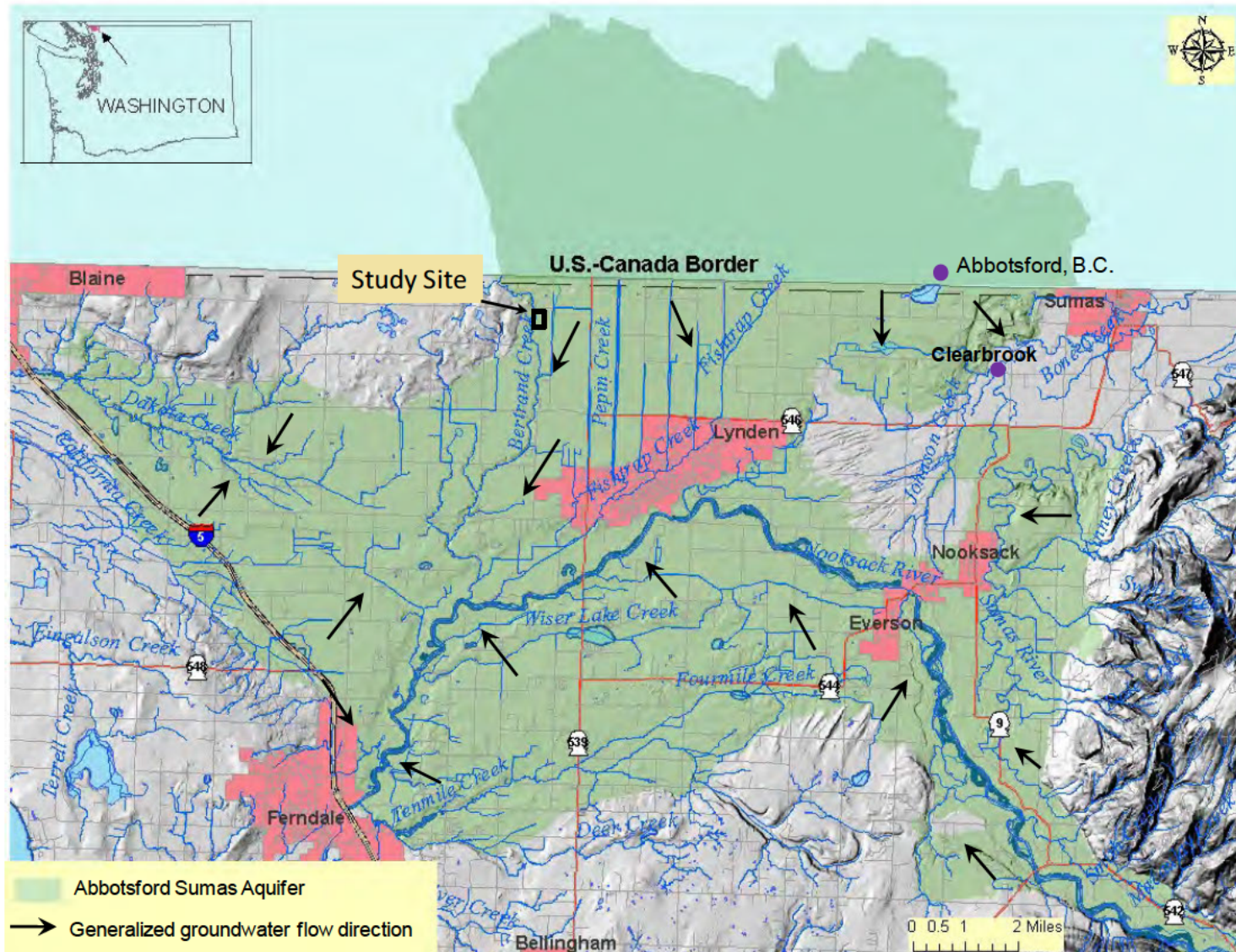


Figure 1. Study site location within the Abbotsford Sumas Surficial Aquifer.
 Groundwater flow direction arrows are from Erickson (1998) and Graham (2008).

Location and setting

The study site is a 22-acre grass field located in northwestern Whatcom County, Washington about three miles north of the town of Lynden and 0.3 mile south of the Canada border (Figure 1). Bertrand Creek, a perennial tributary of the Nooksack River, lies about 200 feet west of the western boundary of the site. The site lies on the flat Lynden Terrace, a glacial outwash plain that slopes gradually southward to the Nooksack River. The site elevation is approximately 130 feet (NAVD88).

Dairy wastewater/nutrients (hereafter referred to as manure) are typically applied as fertilizer on grass and corn fields, which are in turn harvested for stock feed. Approximately 11 to 14 million pounds of manure nitrogen were applied to fields in Whatcom County in 2010 (Prest, 2011). Larger amounts of manure were probably applied across the SBA over the past 40 years, when more dairy cows were present. However, the loading rate (lb/acre) was probably lower than it is currently, because the amount of cropland available for manure application was higher than today.

Berry-growing is also widespread in Whatcom County, in particular raspberry production. Whatcom County is the largest raspberry-growing area in the U.S. Inorganic fertilizer, the main nitrogen source for berries, is easily leached if not taken up by the crop. Loo and Ryan (2012) found that common irrigation practices for raspberries can result in most of the inorganic fertilizer leaching below the root zone and into groundwater. Other crops grown in the area include blueberries, strawberries, seed potatoes and nursery stock.

On the Canadian side of the aquifer, poultry production and berry crops are intensive agricultural activities. Dairy farming is also practiced in the Abbotsford area. Both poultry and dairy production involve land application of manure. Inorganic nitrogen is also applied to berries in British Columbia.

The study field is surrounded by manured dairy fields. However, directly upgradient of the field lies a residence on a 3.5-acre lot. Another residence just west of the upgradient residence may also at times be somewhat upgradient of the site. Both residences were constructed in the past 10 years with on-site sewage systems. The residence slightly west of upgradient also had from 2 to 5 horses or cows present during the study.

Climate

The regional climate is maritime due to proximity to the Pacific Ocean. The Cascade and Rocky Mountains east of the site protect the area from cold air that otherwise would blow down from Canada. The mountains also cause moisture rising off the ocean to drop 32 inches/year of precipitation in the southwestern part of the SBA. Precipitation rates increase to 50 inches/year closer to the mountains in Abbotsford, British Columbia.

Precipitation and air temperature

Precipitation data for the period 1970 to 2010 at Clearbrook, Washington (NOAA, 2011) indicate that the average precipitation in the area is approximately 35 inches. Two-thirds of the annual precipitation in the area typically occurs between October and March. Little rainfall occurs in the summer. Pan evaporation at the nearby Bellingham airport is typically over twice the precipitation rate from June through August (Cox and Kahle, 1999). Where available, irrigation water is applied to crops in the summer.

A battery-powered Onset weather station was installed in the field for the study (Ecology weather station). Precipitation and air temperature measurements were recorded every 15 minutes between September 22, 2004 and March 18, 2009 except for occasional malfunctions. The WSU weather station at the site provided data for 3 months in 2008. Data from the www.wunderground.com “KWALYNDE1” site 3 miles south of the study site in Lynden, Washington were also used during periods when both the Ecology and WSU weather stations were not functioning (Figure 2). For 2004 during the months before the weather station was installed at the site and for 13 days in the summer of 2006, precipitation was estimated as 65% of the precipitation at the Abbotsford, B.C. airport, because daily precipitation at the site averaged 65% of that at Abbotsford.

The annual precipitation at the site ranged from 36.4 inches in 2005 to 48.1 inches in 2006 as shown in Figure 42 (Data in Appendix T). Excluding 2005, the annual precipitation exceeded the long-term average by 25 to 37% during the study (Miller, 1973 and NOAA, 2012).

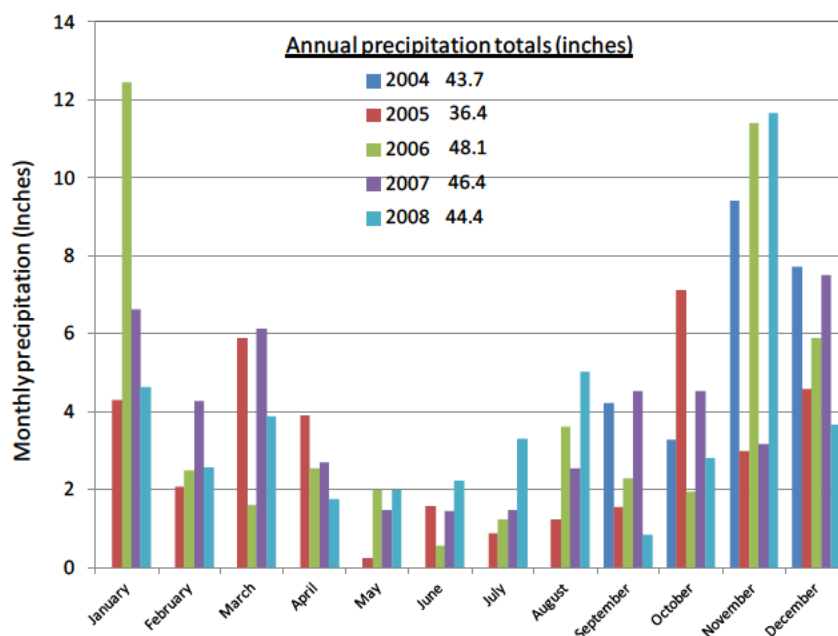


Figure 2. Monthly precipitation at the study site for most dates.
(Appendix Table T.1).

Table 1 shows the annual daily average minimum and maximum air temperature during the study (Data are shown in Appendix Table T.2).

Table 1. Annual minimum and maximum daily average air temperature.

Year	Minimum	Maximum
2005	-5.4	20.5
2006	-10.2	23.9
2007	-7.3	25.7
2008	-9.8	25.0

Recharge

Recharge to the SBA is from precipitation, irrigation, and upgradient groundwater flow. Recharge largely occurs between October and April, when precipitation exceeds evapotranspiration (Cox and Kahle, 1999).

Maps of recharge estimates by Cox and Kahle (1999) and Kohut (1987) show recharge estimates of 16 to 30 inches/year for most of the SBA with increasing rates toward the east.

Large areas of the SBA are artificially drained to lower the water table below the root zone of crops, which prevents a portion of the infiltrating water from reaching the water table (Cox and Kahle, 1999). The drains typically operate during the winter and early spring, the time when most recharge occurs. The effect of the drain system on regional aquifer recharge rates has not been quantified.

Soils

Hale silt loam soil overlies the study site. Hale soils are part of the Lynden-Hale-Tromp grouping that overlies much of the SBA. The subsoil at the site (11-27 inches) is mottled, indicating periodic reducing conditions.

When not artificially drained, the rooting depth for crops in Hale soils is limited by a seasonal high water table of 1 to 2 feet (U.S. Soil Conservation Service, 1992). Other characteristics of Hale silt loam include (U.S. Soil Conservation Service, 1992):

- 5-foot depth
- moderate permeability in the top 16 inches (0.6 to 2.0 inches/hour) and very rapid below that (greater than 20 inches/hour)
- Clay content 10 to 18%
- Organic matter content 3-9%
- pH 5.1 to 6.5

Hydrogeology

Regional hydrogeology

The study site lies in the Fraser-Whatcom Lowlands, also referred to as the Lynden Terrace, a glacial outwash plain that slopes gently south toward the Nooksack River. Repeated glacial advances and retreats during Pleistocene times deposited 1,000-2,000 feet of sediments over the area (Figures 3). Outwash from the last glacial episode, the Sumas Stade of the Fraser Glaciation, left gravel and cobble deposits near the Canadian Border. These deposits grade finer southward to sand and some clay layers in the Lynden area (Easterbrook, 1971).

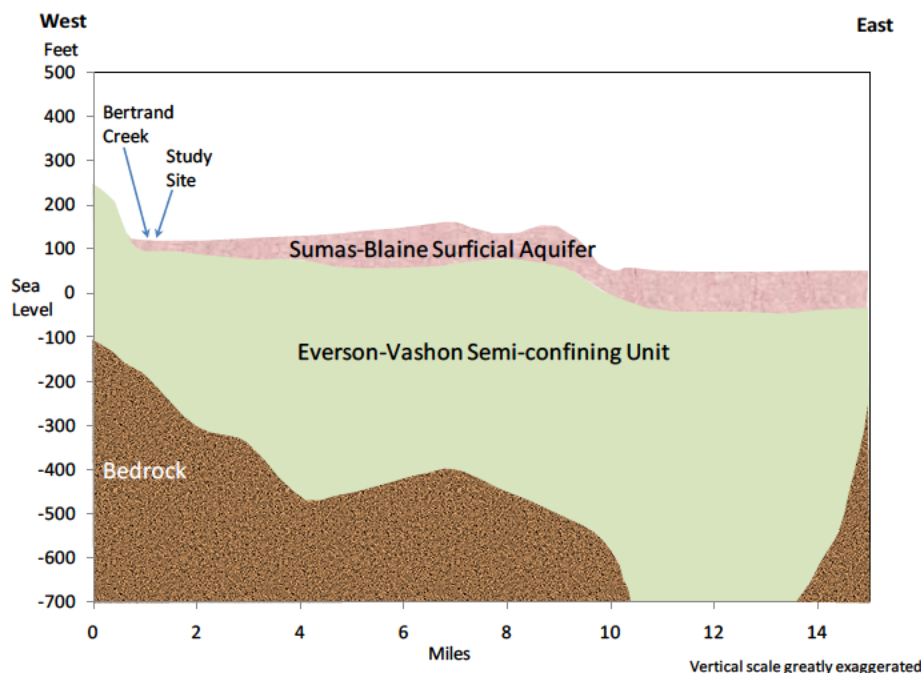


Figure 3. Generalized east-west cross-section near the study area.

Adapted from Cox and Kahle, 1999 and Tooley and Erickson, 1996.

During the past 10,000 years, the Nooksack and Sumas rivers have eroded and reworked the glacial deposits, resulting in the current flat, terraced flood plain morphology. The river has redistributed both the glacial and alluvial material, leaving gravel deposits in upstream areas, and sand and silt downstream.

The principal hydrogeologic units in the study area are shown in Figure 3 and include:

1. Sumas-Blaine Surficial Aquifer (SBA)
2. Everson-Vashon Semiconfining Unit
3. Bedrock

Sumas-Blaine Aquifer

The SBA is about 150 square miles in area and makes up the southern portion of the combined international aquifer system referred to as the Abbotsford-Sumas Aquifer (Figure 1). The SBA consists of stratified, unconsolidated sand and gravel outwash with minor clay lenses. Outwash grades from pebble-cobble alluvium just north of the Canada border in Abbotsford to sand with interbedded fine-grained lenses southwest of Lynden (Cox and Kahle, 1999).

The depth to water is less than 10 feet over all but a small portion of the aquifer in the east, making it highly susceptible to surface contamination (Tooley and Erickson, 1996). A system of ditches and tile drains control high water table conditions and facilitate agricultural use in much of the area. Re-routing of a large portion of infiltrating water via tile drains prevents attenuation of leaching nitrate by denitrification and can quickly direct nitrate-rich leachate to surface water (Keller et al, 2008).

The regional groundwater flow direction is generally north to south in the northern part of the SBA (including the study site), toward the Nooksack River (Figure 1). However, local groundwater flow direction can vary (Tooley and Erickson, 1996; Graham, 2013).

The average saturated thickness of the SBA ranges from 25 feet near Blaine in the west to 75 feet near Sumas in the east, thinning at the margins of the alluvial plain (Figure 3). The study site is situated on SBA sediments at the northwestern margin of the plain (Figure 4, Plate 1).

Everson-Vashon Semiconfining Unit

The Everson-Vashon semiconfining unit is composed of glaciomarine drift consisting of unsorted pebbly clay and sandy silt (Cox and Kahle, 1999). This unit typically functions as a confining bed below the SBA but also includes local coarse-grained water-bearing lenses as thick as 30 feet. The Everson-Vashon unit is typically 100 to 200 feet thick in the study area and thickens to 400 to 700 feet thick in the central axis of the aquifer. High groundwater ion concentrations and difficulty locating coarse-grained lenses preclude the Everson-Vashon unit from consideration as a reliable water supply. The confining layer also prevents significant transport of nitrogen to deeper zones.

Bedrock Unit

The bedrock unit underlying the Everson-Vashon semiconfining unit consists of sandstone, mudstone, conglomerate, and coal of the Huntingdon and Chuckanut Formations (Cox and Kahle, 1999 and Creahan and Kelsey, 1988). This unit is not widely used for water supply due to depth and variable water-bearing properties. However, Cox and Kahle (1999) found records for 24 water wells that apparently connect with fractures where the unit is closer to the surface.

Study site hydrogeology

The study site is located on the western edge of the SBA, an area dominated by finer-grained material compared to most of the aquifer. The depth to the bottom of the aquifer is 40 feet at the site based on well borings drilled at the site (Appendix B, Well AKG726).

Figure 5 (Plate 1) shows the study site and nearby wells used to develop hydrogeologic cross-sections (Figure 6, Plate 1). Since water level measurements shown on the cross-sections are from domestic and monitoring wells measured during different years, the water table position is an approximation. Where possible, low water table measurements for the fall were illustrated on the sections.

Surface water and groundwater from the site flow generally toward the Nooksack River 5.5 miles south of the site. Localized seasonal reversal of the direction of the horizontal hydraulic gradient in the near vicinity of Bertrand Creek also probably occurs, but was not measured in on-site monitoring wells.

Aquifer properties

Hydraulic conductivity of the aquifer sediments varies widely over the SBA. Based on specific capacity estimates from driller's logs, Cox and Kahle (1999) reported horizontal hydraulic conductivity values in the SBA ranging between 7 and 7,800 feet/day, with a median value of 270 feet/day. Although hydraulic conductivity values varied dramatically over short distances, higher values tended to occur near the Canada border in the northeast part of the SBA, and lower values in the western and southwestern part of the aquifer. Site specific measurements of hydraulic conductivity from study monitoring wells are discussed later in this report.

Cox and Kahle (1999) estimated horizontal groundwater velocity throughout the SBA at 0.2 to 29 feet/day based on specific capacity-derived hydraulic conductivity data for 218 wells. For most of the aquifer, they indicated that 2.5 feet/day is a reasonable estimate. Erickson (1992) estimated a groundwater velocity of 1-2 feet/day at a site 2 miles east of the study site using chloride as a tracer. Other velocity estimates for the SBA include 0.3 foot/day 1.8 miles southeast of the study site, based on short-term pumping test results at monitoring wells (Carey, 2002), and 25 feet/day in the coarser-grained Judson Lake area 7 miles east of the study site, based on modeling results (Stasney, 2000).

Dairy nutrient management plans

The Washington State Dairy Waste Nutrient Management Act (Chapter 90.64 RCW) of 1998 requires that all dairies develop Dairy Nutrient Management Plans (DNMPs). The primary objective of the law was to ensure that surface water and groundwater quality in the state are not adversely affected by dairy manure. DNMPs were required to be approved by July 1, 2002, and implemented with final certification by December 31, 2003. These plans were submitted to local conservation districts for review and approval.

A primary goal of the DNMP's is to balance nutrient application and plant uptake on each individual farm. One aspect of this goal is that the amount of nitrogen removed in the crop match as closely as possible the amount of nitrogen available from the combination of manure nitrogen and nitrogen released from organic material in the soil. In this study, roughly 50% of the manure nitrogen was almost immediately plant-available, while the other 50% was in the organic form and gradually converted to plant-available forms over time.

DNMP's are required to outline steps necessary to ensure proper handling and use of dairy waste. Because most of the land on a dairy farm is manured fields, the focus on nutrient management is vital for addressing groundwater nitrate issues. This is particularly true in areas of known vulnerability to groundwater nitrate contamination, like the SBA.

One requirement of DNMP's is that one composite fall-season soil nitrate analysis be taken at each field receiving dairy nutrients soon after the last harvest. Results of the fall soil nitrate test are used to evaluate the balance between the amount of nitrogen applied and the amount removed by the crop (Sullivan and Cogger, 2003). Sullivan and Cogger established a post-harvest soil nitrate threshold of 15 mg/kg (55 lb/acre) below which manured fields did not need to make changes to current management practices. However this target was not developed to address impacts of nitrate leaching to groundwater.

The timing of fall soil nitrate sampling can have a critical effect on nutrient balance evaluations. It is recommended that soil nitrate samples be collected soon after the last harvest. If fall soil sampling occurs after a sizable rainfall, the results may represent only what is left after at least a portion of the residual nitrate has leached below the sample depth (one foot). If sampling occurs before the last manure application for the year, the result probably under-represents the amount of nitrate available for leaching during the rainy season. Hirsch (2007) found that soil nitrate sampling after harvest did not capture all of the nitrate leached below the root zone. She recommended testing soil nitrate at the same time as harvest to avoid missing leaching losses. The potential for wide variability in soil nitrate result over short time spans suggests that the standard practice of collecting a single fall soil nitrate sample is a potentially poor predictor of the amount of nitrate that will ultimately reach the underlying water table.

The Washington Department of Agriculture is responsible for overseeing dairies and DNMP's, but the legal authority is weak for ensuring that DNMP's are followed or updated as facilities, land base, or herds change.

Local dairy field management

Over the past 20 years the method of applying manure to crop fields has changed from mainly large capacity "big gun" spraying and spreading with tanker trucks to methods that splash or inject manure into shallow slits in the ground. These newer methods result in less ammonia volatilization and a reduction in odor.

Dairies in western Washington typically begin to apply manure to forage crops in the spring when weather and soil conditions are conducive to machinery traffic, crop uptake of nutrients is more active, and the risks of surface and groundwater contamination from bacteria and nitrate are reduced.

Non-application periods for grass fields in non-flood areas of Whatcom County are typically November 1 through February 15 or during periods when the T-Sum value is less than 200 (aka T-Sum 200).¹

¹ The T-Sum value is derived by summing the daily mean temperature (in degrees Celsius) starting January 1st of each year. (Ord. 98-074; Ord. 98-056--Whatcom County Code 16.28.030
<http://www.codepublishing.com/wa/whatcomcounty/frameless/index.pl?path=../html/Whatco16/Whatco1628.html>)

Negative mean temperatures (below zero degrees Celsius) are assigned a zero value, i.e., not subtracted. In areas with potential flooding, the non-application period begins October 15 or 30 days prior to the typical flood season (November 15 for the Nooksack River).

The above ordinance also states that, “Should favorable climatic conditions exist, application may begin earlier in the spring than the dates established in this chapter, following approval from the Whatcom Conservation District board based on T Sum 200 or best available science. Soil conditions must also be considered when deciding when to apply nitrogen.”

NRCS (2005) provides guidance for nutrient management planners regarding conditions for winter manure application. Whatcom Conservation District is testing a method for incorporating site-specific weather and field conditions into manure application timing and amounts (Application Risk Management) (Embertson, 2010).

In addition to manure, dairy producers may supplement manure applications with commercial inorganic nitrogen fertilizer during the summer. Irrigation water is applied on many fields during the dry summer months. Grass crops are typically harvested 4 to 5 times per year.

Field management at the study

The 22-acre study field has received manure for over 20 years at about the same application rate as during the study, according to the producer (~400 to 700 lb total N/acre/year). The site was planted in grass before the study and was tilled and re-seeded back to grass in April 2004 four months before sampling began using conventional tillage practice. Conventional tillage practice includes subsoiling, rotatilling, plowing, disking, seedbed preparation, culti-mulching, and planting (VanWieringen, 2009).

During the study the dairyman managed the field as before the study. The first liquid manure application for the year occurred in February, March, or April each year depending on weather and soil conditions. Manure was applied most often using subsurface deposition using equipment from Aerway® Aerators & Parts (Figure 7). Tines were set 7.5 inches (19 cm) apart on a roller and allowed to drop 4 inches (10 cm) below the soil surface creating intermittent slices 5 inches (12.5 cm) deep at the surface. Tines wear down over time and may be shorter and slices less than 5 inches (Clark, 2013). Liquid manure was sprayed over the slices.

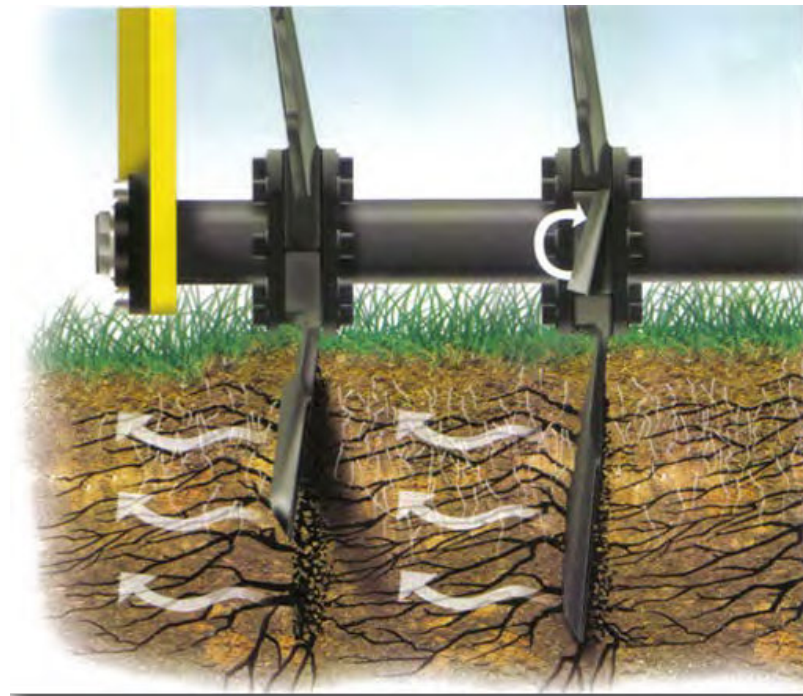


Figure 7. Sub-surface deposition of manure at the study site (top) and close-up diagram (bottom from Aerway® Aerators & Parts).

waiting for permission to use this graphic).

(My Doc's/Data/Tillage Study/Photos/aerator good close-up-2—5_18_10.jpg)

On 3 out of 17 occasions liquid manure was applied by injection, which is similar to subsurface deposition except that the manure is injected a few inches below the top of the soil.

Manure was typically applied 3 to 5 times per year following each grass cutting except for the last cutting. In 2005 and 2008, part of the summer manure application was from a nearby dairy (VanWieringen and Harrison, 2009). Manure was applied after the last harvest in 2005 and 2006. The final manure application for the season occurred between the end of August and early October.

Irrigation water from a nearby shallow well was applied at the study site using a hard-hose reel with a “big gun” sprinkler and pump each summer. As is typical for the area, the grass crop was harvested 4 to 5 times each year with the field left idle through each winter.

Nitrogen cycle

Nitrate is part of the dynamic system of nitrogen-containing compounds transformed in the environment and referred to as the nitrogen cycle. This section describes the major parts of the nitrogen cycle that occur at a typical manured field over the SBA.

Figure 7 shows the main components of the nitrogen cycle for the study site during the two main agricultural seasons. The top diagram in Figure 8 represents the spring/summer period, when the water table is several feet below the root zone of the grass crop. The vadose zone includes the root zone [roughly 0 to 3 feet BGS (below ground surface)] and extends to the water table, which during this drier season is roughly 10 feet BGS.

The bottom diagram in Figure 8 shows the late fall/early winter scenario after heavy precipitation has raised the water table to within roughly 1 to 3 feet of the surface, frequently intersecting the root zone.

The first manure application to grass crops typically occurs in early spring, and additional applications are made after each cutting through the summer. The final yearly manure application usually occurs in September or October following the last grass cutting. Ammonium typically makes up roughly 50-70% of the nitrogen in liquid manure, with organic nitrogen making up the remaining 30-50%.

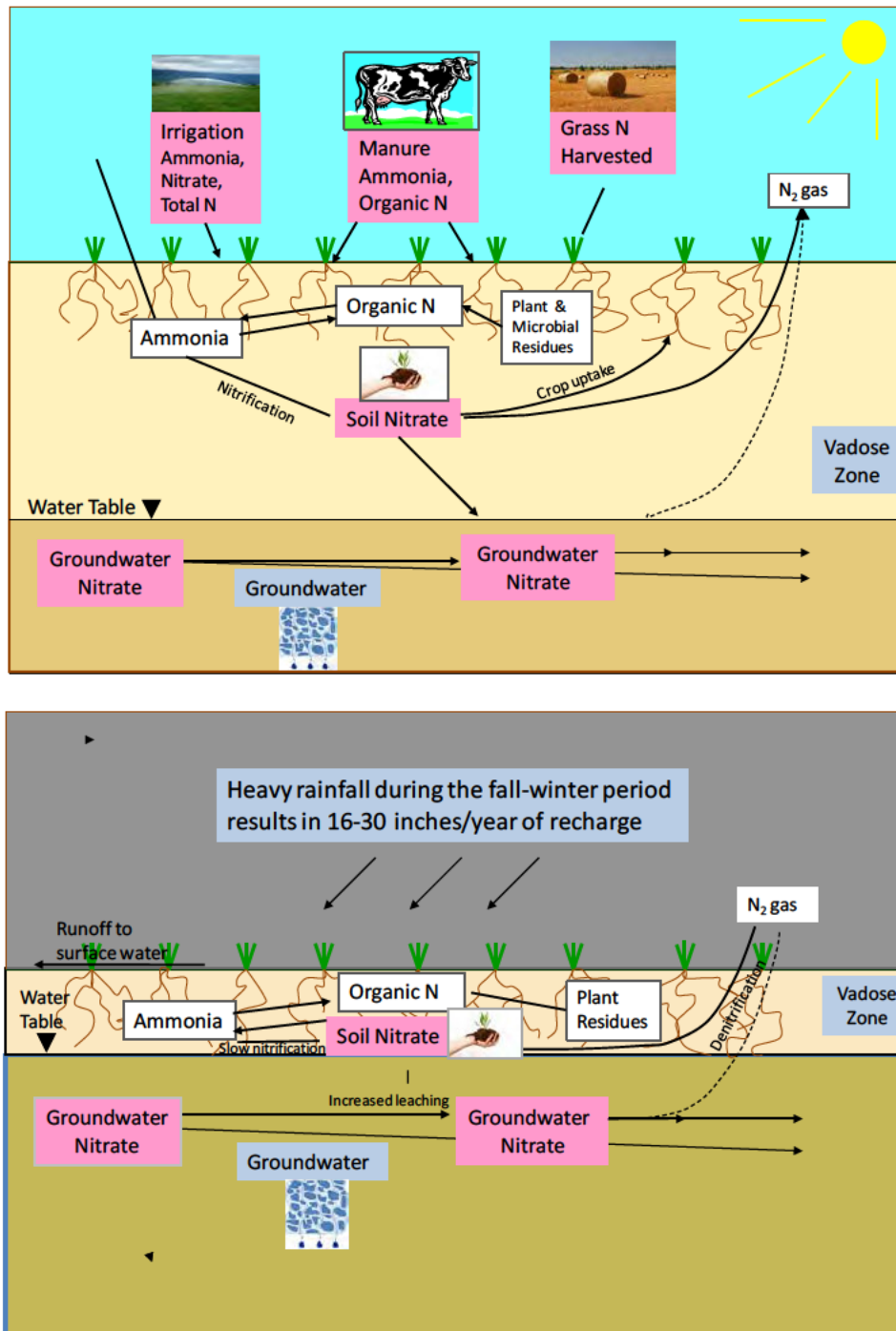


Figure 8. Major nitrogen transformations in the spring/summer period (top) and fall/winter (bottom) at the study site.

Media in the pink boxes were measured during the study.

Recharge estimate is from (Cox and Kahle, 1999)

Volatilization

A portion of the liquid ammonium contained in manure converts to ammonia gas after application and volatilizes to the atmosphere. The amount that volatilizes depends on the application method, weather conditions (especially wind, rainfall, and temperature), and soil conditions. Most volatilization occurs during the drying process soon after manure is applied (Beegle et al, 2008; Sullivan, 2008). Therefore rainfall or saturated soil conditions during or shortly after application can significantly limit volatilization. If ammonium infiltrates into the soil before drying, then less ammonia volatilizes than if drying had occurred. Soil conditions also influence ammonia volatilization. Volatilization is higher where soil pH is high and cation exchange is low (Beegle et al, 2008).

Subsurface deposition, the principal method of manure application used at the study site, reduces the amount of ammonia volatilized to about 10 to 15% (Clark, 2012) compared to 20 to 59% for spray application methods (Pfluke et al, 2011). Even when applied using more traditional methods of aerial spraying, ammonia volatilization decreases if the manure is incorporated into the soil soon after application (Sullivan, 2008).

Mineralization (ammonification, immobilization/assimilation)

Mineralization is the general term for conversion of organic nitrogen to ammonium (NH_4^+) and ultimately nitrate (NO_3^-) by bacteria. The rate of mineralization is affected by temperature, soil moisture, and the redox condition of the soil. Ammonification is the first step in the mineralization process. Roughly one-third to one-half of the organic nitrogen in land-applied manure mineralizes quickly to ammonium, while the more resistant portion converts gradually over time in a decay process (Beegle, et al, 2008). Although ammonium can be taken up by the crop, nitrate is the preferred nitrogen form for plant uptake. Microorganisms can also take up ammonium and immobilize nitrogen in terms of crop availability.

Nitrification

Nitrification, the second step in the mineralization process, is the bacterial conversion of ammonium to nitrate. This is usually a rapid process favored by warm temperatures, adequate moisture, and aerobic conditions. Although the optimum temperature for nitrification in cultured bacteria from soil is in the range of 25 to 30 C, studies have shown that nitrification also occurs at colder temperatures typical of winter conditions (Norton, 2008). During the winter the rate of mineralization is slower than during the warmer seasons (Trindade et al, 2001; Zhao et al, 2010; Cookson et al, 2002).

Nitrification is limited in very wet and very dry conditions. In the summer, if the soil moisture becomes too low, bacteria become dehydrated, and nitrification is severely slowed (Norton, 2008). Saturated winter conditions can also inhibit nitrification due to reduced oxygen.

Lower nitrification rates have been observed in soils with pH of 4.7, but nitrification rates for soils with pHs of 5.3 to 6.6 were all similar. The nitrification rate for Hale silt loam, the predominant soil type at the study site (pH 5.1-6.5), should not be affected by pH unless the actual pH at the site is lower than typical.

Crop uptake

Nitrogen is the main limiting nutrient for most crops. Nitrate is the most available form of nitrogen for plant root uptake due to its much higher solubility compared to ammonium (Olson and Kurtz, 1982). Positively charged ammonium ions react with negatively charged soil particles (particularly clay particles), keeping them relatively stationary in soil. However, plant roots readily take up ammonium, if available, especially in the spring before nitrification increases. During the winter months grass crop uptake rates are slower than during the growing season.

Denitrification

Denitrification is the reduction of nitrate under anaerobic conditions (low oxygen) by bacteria to nitrogen gas. In soil anaerobic conditions are usually caused by saturation. Denitrification requires the transfer of electrons from a donor such as organic carbon. Dissolved organic carbon is a component of organic material (including manure) and is the common electron donor for the reaction (Green et al, 2008; Desimone and Howes, 1996). Organic carbon from manure can build up in the soil over time and enhance the denitrification potential in the soil. Nitrate can also be reduced either bacterially or chemically where iron or sulphur are the electron donors (Buss et al, 2005).

Like the nitrification process, the reaction rate for denitrification increases with temperature with an optimum in the range of 25 to 35° C (Buss et al, 2005). Rates of denitrification are known to be highly variable over small distances. “Hot spots” are often reported in soils where denitrification rates are much higher than those in nearby locations (Coyne, 2008). Denitrifying bacteria are most abundant in the surface soil and decrease with depth. Denitrifying bacteria are less active in acidic soils with pH less than 5 than soils with pH 6-8 (Buss et al, 2005).

Denitrification can occur in both the vadose zone and in groundwater. Denitrification in groundwater is most likely when dissolved oxygen and oxidation-reduction potential are low and organic carbon is available (Singleton, et al., 2007; Gillham and Cherry, 1978).

Leaching

In the fall and winter, percolating water due to heavy rain in western Washington dissolves unused nitrate in the soil and carries it past the root zone, through the vadose zone to the water table. Because of its high solubility, most, if not all, excess nitrate remaining in the soil after the growing season leaches to groundwater in the fall to early winter (October to January) (Beegle, et al, 2008; Downing, 2008; Hermanson, et. al, 2000; Zebarth, et al, 1998; Paul and Zebarth, 1997; Kowalenko, 1989 and 1987). Ammonium is either held in the soil or mineralized to nitrate and is therefore not normally found in the dissolved phase at the water table.

The water table typically rises to within 0 to 3 feet of the ground surface at the study site during the winter. The lowest water table depths, 9 to 11 feet BGS, occur in the fall. Lingered nitrate in the soil not picked up by percolating water may become submerged by the rising water table and dissolved into the groundwater.

While the grass crop is actively growing in the summer, leaching is normally negligible unless irrigation water, which is used on some fields over the SBA in the summer, is over applied. High evapotranspiration rates in the summer make it difficult to exceed the uptake capacity for grass.

Leaching may also occur in the late winter/early spring, when precipitation exceeds evapotranspiration and plant uptake of nitrogen is low (Chesnaux et al, 2007; Zebarth and Paul, 1997;). Trindade et al (2001) found high nitrogen mineralization rates during the winter when soil temperatures were above 5°C and soil moisture was near field capacity. If not taken up by plants, this newly generated nitrate can be readily transported to the water table.

Study Design

Our study approach included:

- Conducting a 4-½-year intensive multi-media monitoring program at a 22-acre manured dairy field
- Analyzing the study field nitrogen mass balance each year and comparing the estimated nitrogen residual to shallow, underlying groundwater nitrate concentrations
- Evaluating the effect of various environmental and management factors on the nitrogen mass balance and groundwater nitrate concentrations

Our monitoring program focused on the following components of the nitrogen cycle to evaluate the balance of nitrogen at the study field, as shown in Figure 9:

- Inputs
 - Manure and inorganic fertilizer (mass of nitrogen applied to the field)
 - Irrigation water (volume and nitrogen concentration added to the field)
- Outputs
 - Grass harvested (mass of nitrogen removed from the field)
- Residual
 - Soil (fall nitrate mass; mass of nitrogen remaining in the upper root zone at the end of the growing season)
 - Groundwater at the water table (nitrogen concentration)

Nitrogen outputs due to volatilization and denitrification processes were also estimated using methods outlined in NRCS (1998).

To support the mass balance evaluation, additional field work was conducted to characterize the hydrogeology and soil characteristics of the study site. This included:

- Measuring static water levels in monitoring wells,
- Conducting tests of the hydraulic characteristics of the unconfined aquifer underlying the study field,
- Conducting grain size analysis of site soil deposits,
- Measuring chloride in groundwater to use as a conservative environmental tracer
- Measuring other water quality constituents in groundwater that contribute to understanding nitrate levels.

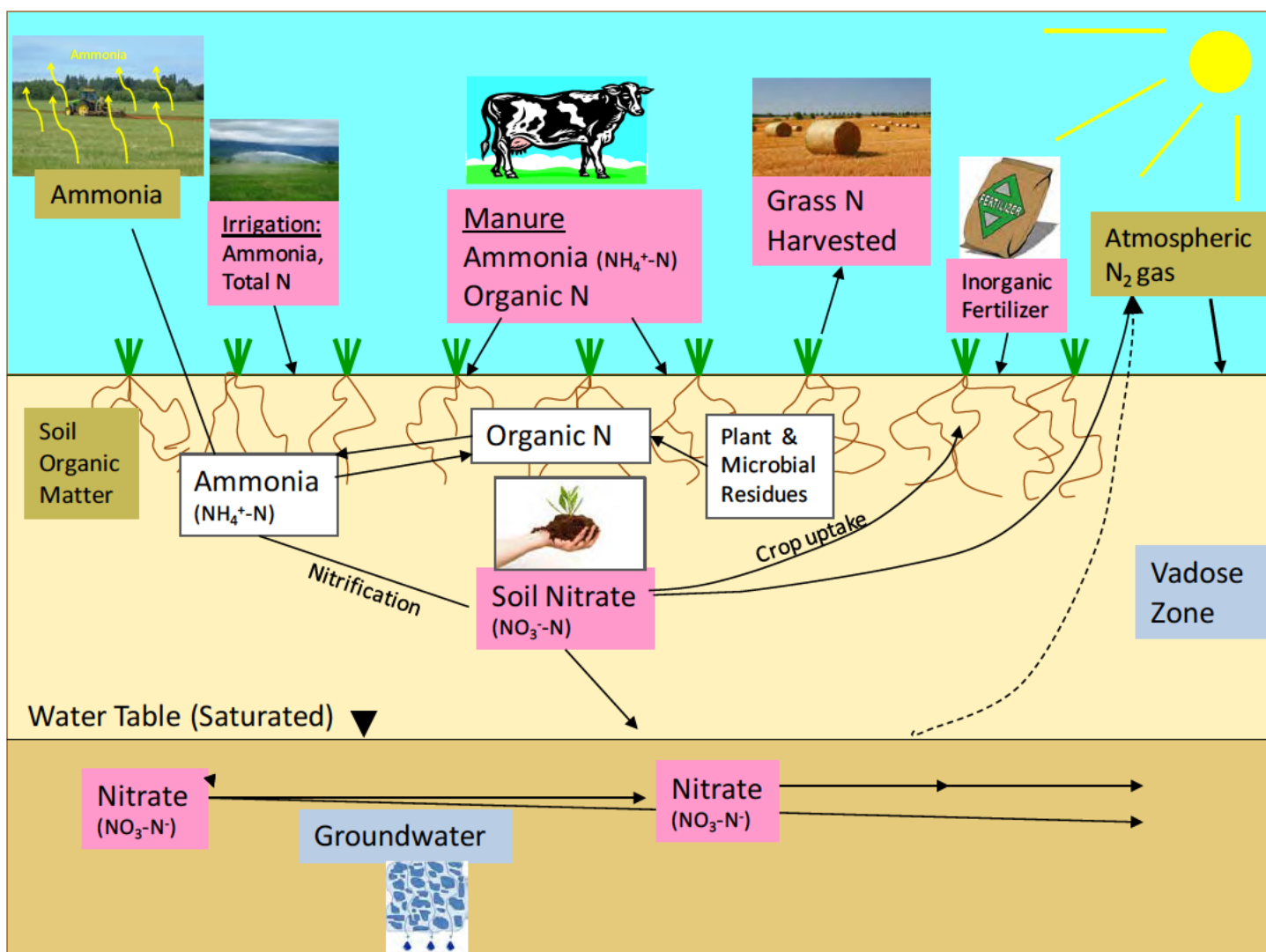


Figure 9. Major nitrogen compartments in the study field.
Media in pink boxes were monitored. Items in brown boxes were estimated.

Further details of the study design are described below and in Carey (2004). Figure 10 shows the analytes sampled in each media. See Appendix C for the list of analytes and sampling frequency.

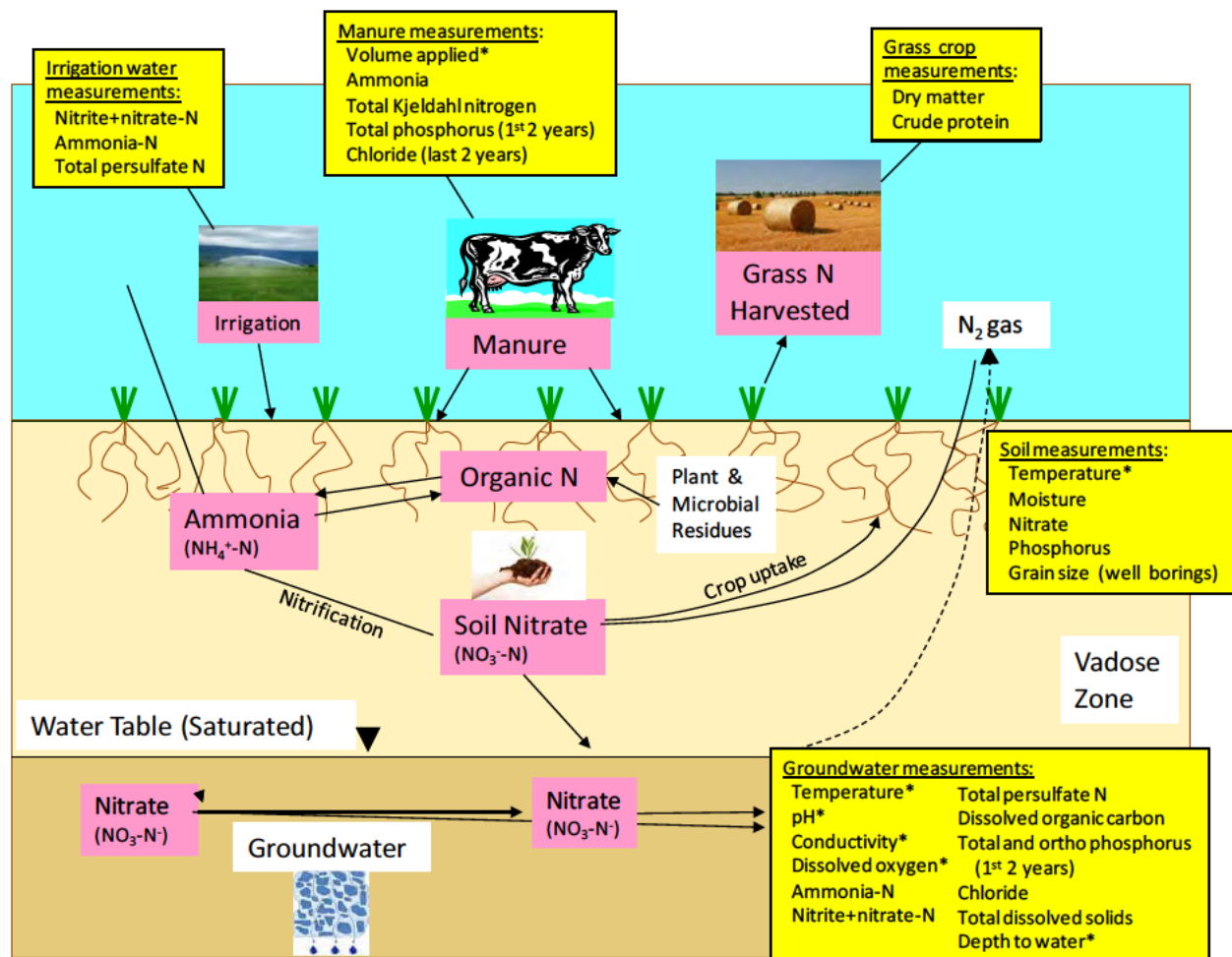


Figure 10. Analytes measured in each media are shown in boxes. Measurements were made in the laboratory except those with *'s, which were made in the field.

Methods

Sampling of nitrogen inputs and related constituents

Manure

Samples of liquid manure applied to the field were collected from the applicator when manure was being applied. We sampled manure 17 out of 18 times that it was applied to the field during the study. Manure was applied 4 to 5 times/year. The SOP for manure sampling is described in Appendix D. The dairy producer reported the amount and timing of inorganic fertilizer application on two occasions, one time each in 2006 and 2007.

Irrigation water

With one exception, irrigation water samples were collected from the irrigation water applicator while the field was being irrigated. In 2005 the amount of water applied during two irrigation events was estimated by the producer. Irrigation water samples were collected into 3 acid-washed buckets twice at different times throughout the irrigation event.

The volume of water collected in each bucket was measured and the rate of application was estimated as:

$$I = (V / T) / A \quad \text{Equation 1}$$

Where

I = Irrigation rate (inches/day)

V = Volume of water in buckets (cubic inches)

T = Time (day)

A = Area of the buckets (square inches)

Contents of the 3 buckets were then composited and mixed in an acid-washed container. The sample was poured into two bottles with preservative and placed in a cooler with ice for shipping via FedEx to MEL. See Appendix E for the detailed SOP.

In addition to nitrate-N, which was analyzed throughout the study, irrigation water samples collected on September 12, 2007 and for both applications in 2008 were also analyzed for ammonia-N and total persulfate N.

Sampling of nitrogen outputs

Grass

Grass samples were collected 1 to 2 days before each crop harvest, 4 to 5 times each year. Five subsamples were composited to form one sample on each date. The process was repeated for a duplicate sample.

The 10 general subsample locations (5 for the sample and 5 for the duplicate) were initially randomly selected and recorded using GPS. The same 10 locations were then sampled each time thereafter. The SOP for grass sampling is described in Appendix F.

Sampling of nitrogen residuals

Soil

The frequency and timing of soil sampling rounds were scheduled to correspond with manure application and precipitation events. Manure application occurred mainly in the dry spring and summer when reduced leaching of nitrate to groundwater is expected. Therefore monthly soil nitrate sampling was sufficient to characterize availability to the crop during the spring and summer.

Precipitation begins to exceed evapotranspiration in the fall, facilitating leaching to groundwater. September to early October is also typically the time when final manure applications for the year are made. Concentrations of nitrate in the soil can therefore vary dramatically over a short period of time in the fall. Depending on the timing and intensity of precipitation, most residual nitrate leaches below the root zone by mid-December.

We sampled soils weekly for nitrate-N from August 2004 through November 2008 and measured soil temperature and moisture at the same time. We conducted soil sampling monthly during the rest of the year (December through July).

Soil sampling Standard Operating Procedures (SOPs) are described in Appendix G. These procedures are summarized below and are based on methods described by Sullivan and Cogger (2003). Soil sampling locations are shown in Figure 11.

Each sample consisted of a composite of 15 soil core subsamples. A one-inch diameter hand-held coring device was used to collect each one-foot deep soil core subsample at initially random locations around the field. The location of each core was verified using a Global Positioning System (GPS). The same locations were re-visited and sampled each subsequent event.



Figure 11. Soil sampling locations.

All sample sites were in the field, although the aerial photo does not provide this level of accuracy.

Loose crop or manure residue at the top of each core was discarded. The remaining soil from each of the 15 cores was placed in a 5-gallon bucket and mixed thoroughly by hand with a properly decontaminated trowel. The composite sample was then divided into 2-3 subsamples and placed in clean plastic bags, one for analysis at the contract lab, one for archival storage at WSU-Puyallup. Once each year an additional composite sample was sent to a contract lab as a replicate.

A duplicate set of soil cores was collected each sampling day at a different set of 15 locations than were initially randomly selected. The duplicate sample was treated the same as the first sample. Subsequent soil cores were collected within a few feet of the original 30 duplicate locations.

Soil samples were placed in a freezer within one hour of sampling. Frozen samples were placed on ice in a cooler and shipped overnight via FedEx to the contract lab. The archival samples were placed on ice and maintained at WSU, Puyallup, Washington.

Soil temperature was also measured at a 6-inch depth during each soil sampling event. Soil temperature was measured by inserting 2 temperature probes 6 inches into the ground near the first soil coring location.

Groundwater

Nitrate enters groundwater beneath the study field via three major pathways:

- leaching and infiltration of nitrate from overlying soils through the vadose zone,
- direct dissolution of soil nitrate when the water table rises and comes in direct contact with the root zone, and
- lateral groundwater transport of nitrate from upgradient of the study field.

Because of the high solubility of nitrate, infiltrating water can rapidly transport dissolved nitrate through the root zone and eventually to the water table. This process is of particular concern during periods of heavy precipitation (fall/winter/early spring), when the water table rises 5 to 9 feet in elevation. This leaves little chance for nitrate to remain in the thin unsaturated soil layer (Kowalenko, 1989 and 1987; Zebarth et al, 1996).

Because the most recently recharged groundwater is closest to the top of the water table (Figure 12; Wassenaar et al, 2006), we completed the monitoring wells in a manner to intersect the water table and characterize recent recharge.

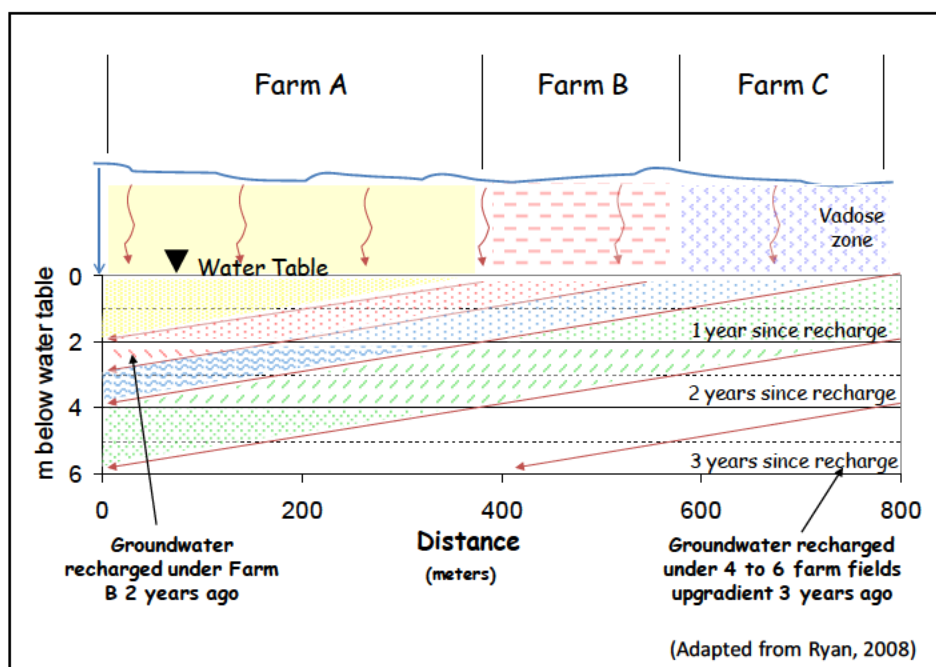


Figure 12. Generalized groundwater flow beneath fields in the Abbotsford area 8 miles northeast of the study site showing that water near the top of the water table represents the most recent recharge from above.

Adapted from Ryan (2008)

Monitoring well installations

Two wells were installed in three rows from upgradient to downgradient in the field (Figure 5, Plate 1). All of the monitoring wells were within the manured field (See Appendix B for drilling logs.) The monitoring well locations and construction specifications were chosen to:

- Describe the subsurface hydrostratigraphy and hydraulic properties
- Estimate the groundwater flow rate and direction
- Obtain samples representative of the most recent groundwater entering the aquifer on the site (top of the water table)

Monitoring wells were installed by Holt Drilling, Inc., Puyallup, Washington, using a 4¼-inch I.D. diameter hollow stem auger (8-inch O.D). The wells were installed from August 25 to 26, 2004, about 4 weeks before groundwater samples were collected. Six wells were 12 to 13 feet deep, and one well drilled to the bottom of the aquifer was 38 feet deep. See Appendix H for a summary of well locations and construction information.

The monitoring wells were constructed according to the state standards for resource protection wells (Chapter 173-600WAC). Figure 12 shows the standard construction plan for the shallow monitoring wells. The deep well was constructed similar to Figure 13 except that the well screen was 10 feet long.

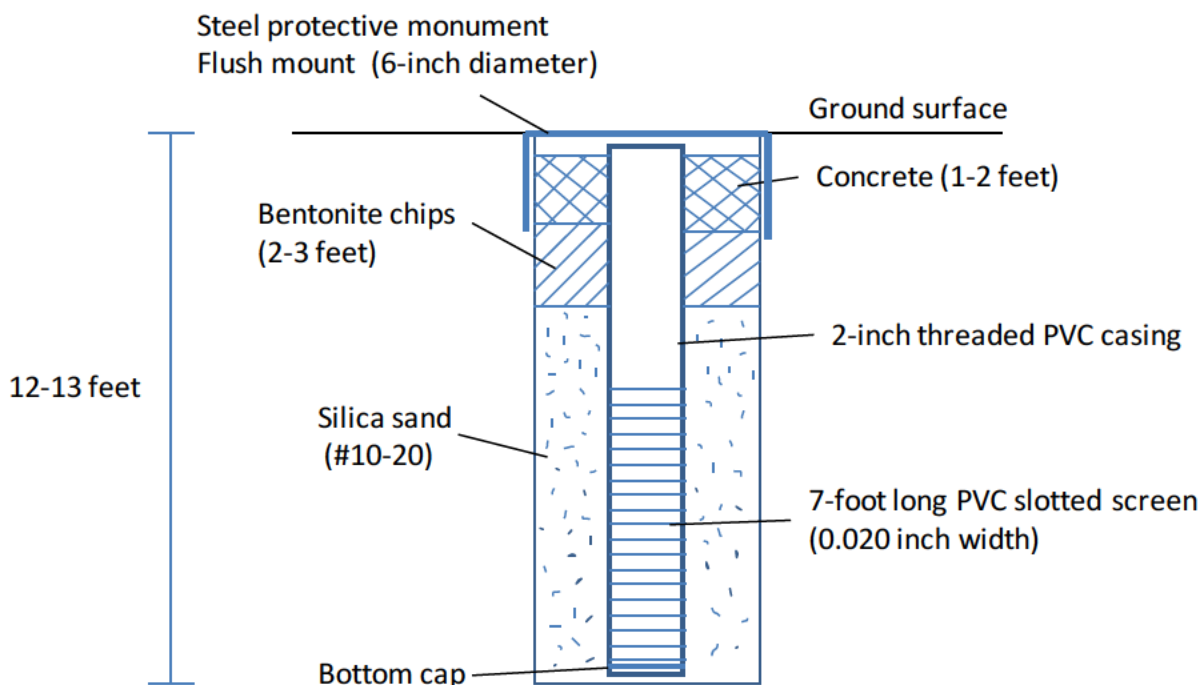


Figure 13. Schematic for shallow monitoring well construction.

Wells were constructed with 2-inch diameter PVC, flush-threaded casing and commercially fabricated 7-foot long screens with a slot size of 20. We selected 7-foot long screens to provide as close to year-round access as possible to the top of the water table, which fluctuates roughly 7 feet over the year.

The sand pack consisted of 10-20 silica sand installed continuously over the screened interval to 1 to 2 feet above the top of the screen. Bentonite pellets were placed within the annular space between the boring and the PVC casing from the top of the gravel pack to within 1 to 2 feet of the surface. Concrete was installed around the top 1 to 2 feet of casing.

Split spoon core samples (18 inches long) were collected at 5-foot intervals during drilling. Core samples were placed in labeled plastic zip-lock bags. A total of fifteen split spoon samples were analyzed from the seven wells for grain size according to ASTM Method D422 (ASTM, 2003). Samples intervals were selected to cover the range of material types encountered and the range of depths. Triplicate samples were analyzed for the deepest sample, 40 feet, in AKG726. The texture of the 40-foot sample changed dramatically from fine sand above 40 feet to clay and silt, indicating the base of the SBA.

Each monitoring well was equipped with a water-tight cap and lock. A steel 6-inch diameter flush-mount outer protective casing was installed over the PVC well. The steel casing extended to a depth of two feet below ground.

After completion, the wells were developed by the driller using a jetting technique until the water removed from the borehole was free of sediment. A state well tag with a unique ID number was attached to each well.

Upgradient private wells

In addition to groundwater monitoring wells installed in the manured field, we sampled 2 upgradient private water-supply wells in 2008, one adjoining the site and one northeast of the site (Marti, 2011a). Well ALQ013 was sampled two times (March 11 and April 2) and APM737 one time on March 11 (see Appendix B for drilling logs). The wells are screened at 29 to 34 feet depth. Analytes included temperature, pH, specific conductivity, dissolved oxygen, ammonia-N, nitrate-N, total nitrogen, chloride, and total dissolved solids. Samples from these wells were not filtered.

Hydraulic testing

We conducted aquifer hydraulic testing to determine if the subsurface hydraulic properties at the study site are similar to those reported for the SBA as a whole. Hydraulic testing helps estimate sediment permeability and groundwater velocity, which affect how quickly nitrate and other dissolved constituents move once they reach the water table.

Short-term specific capacity tests were conducted on April 4, 2006 at three monitoring wells to provide an approximate estimate of the hydraulic properties of the aquifer materials. We tested the deep well (AKG726) and two shallow wells (AKG723 and AKG725) to characterize the shallow and deeper portions of the unconfined aquifer.

A specific capacity test consists of pumping a well at a known rate until the water level in the well equilibrates. The drawdown is recorded throughout the test period and is used with the well construction information to estimate the transmissivity and hydraulic conductivity of the aquifer in the vicinity of the well screen.

Specific capacity refers to the rate of well discharge divided by the drawdown in the well and is measured in gallons per minute per foot of drawdown. Bradbury and Rothschild (1985) developed a technique for estimating hydraulic conductivity using specific capacity based on the Theis' (1963) graphical method. The Bradbury and Rothschild (1985) method uses a computerized iterative procedure to estimate transmissivity, which is then converted to hydraulic conductivity by integrating over the saturated thickness. The method uses the Cooper-Jacob approximation of the Theis equation with corrections for partial penetration and well loss (turbulent flow in the well during the test). See Appendix I for method details.

The assumptions of the Bradbury and Rothschild (1985) technique include:

- Confined, non-leaky, homogeneous, isotropic aquifer
- Storage coefficient is known
- Minimal well loss
- Penetration of the aquifer is known

Despite not meeting the assumptions of confined conditions, Bradbury and Rothschild (1985) had success using the computerized method in unconfined sand and gravel wells of the Central Sand Plain of Wisconsin. They found close agreement between results of full-scale pumping tests and specific capacity tests in individual wells. Sinclair (2002) likewise found hydraulic conductivity results from large-scale aquifer tests and those from specific capacity tests in the Sequim-Dungeness area of Washington to be within a factor of 2. This is close agreement for hydraulic conductivity values, which often vary by an order of magnitude even when using the same method.

Groundwater sampling

The field and laboratory methods used for groundwater monitoring are described in Carey (2004). Standard protocols used in the Ecology EA Program were followed for measuring field parameters and collecting samples for laboratory analysis. Likewise, standard methods were used for sample handling, preservation, and storage (Marti, 2011b).

Groundwater samples were collected monthly during the fall and winter, and every six weeks in the spring and summer. Prior to sampling, water levels were measured at each well using a clean, calibrated electric probe per methods (Marti, 2009). Measurements were recorded to 0.01 foot and are considered accurate to 0.03 foot.

For well purge and sampling, we used a peristaltic pump with dedicated high density polyethylene tubing that remained inside the well between sampling events. A short section of silastic tubing at the pump head was used for all shallow wells and was replaced for each new sampling event. The pumping rate for the shallow wells was approximately 0.11 gallon/minute.

The intake for the sample tubing was set at 1.5 feet below the top of the water table, or at the top of the screened interval when the water table was above the screened interval.

We purged and sampled the deep well (AKG726) using a submersible pump with dedicated polyethylene tubing. The pumping rate for purging and sampling at well AKG726 was approximately 1 gallon/minute.

We purged each shallow well for a minimum of 20 minutes and until field parameters stabilized to within 10% for consecutive measurements spaced five minutes apart (temperature, pH, conductivity, and dissolved oxygen). The deep well was purged for 3 to 5 minutes, because the flow rate was high enough that field parameters stabilized quickly. Field parameters were measured inside an enclosed flow-through cell to minimize atmospheric bias effects (Figure 14).

Samples from the shallow wells were field-filtered using dedicated, in-line 0.45 μm filters. After discarding the initial 50 mls of filtrate, the samples were collected in clean bottles obtained from the Manchester Environmental Laboratory (MEL), as shown in Figure 15.

Samples collected from the deep well were not filtered. The higher discharge rate from the submersible pump used for the deep well made it more difficult to use field-filters. The discharge from the deep well was visually clear, and we assumed that the constituents of interest would not be in the particulate form.

Results for nitrate+nitrite-N analyses are referred to as “nitrate-N” in this report, because nitrite-N is typically negligible in groundwater (Sawyer and McCarty, 1978).

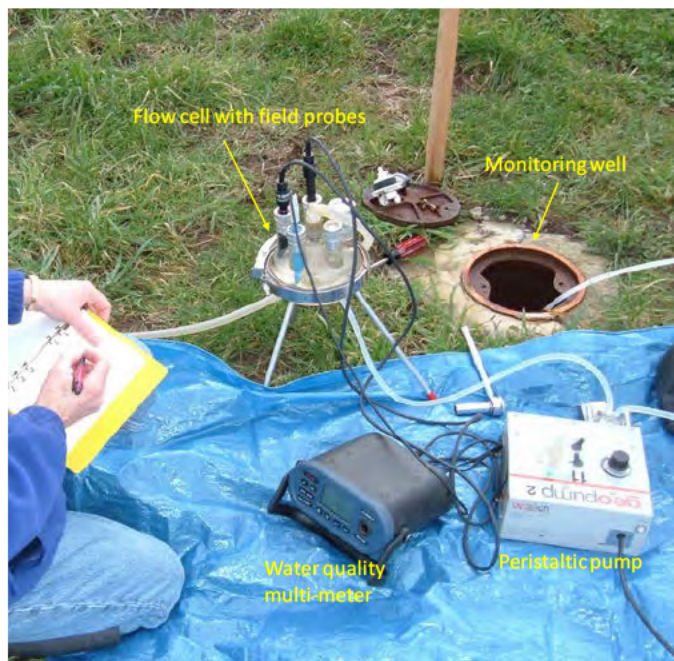


Figure 14. Groundwater sampling flow cell, peristaltic pump, and multi-meter for measuring field parameters: temperature, pH, conductivity, and dissolved oxygen.



Figure 14. Field-filtering a groundwater sample using a disposable, in-line filter that by-passed the flow cell.

Quality assurance

Results of quality assurance (QA) testing for each media sampled are described in Appendix K and summarized below. Overall, the results of the QA testing indicated that the analytical data collected during the study are of good quality and can be used without qualification. In a few cases qualifiers were added to a data result to identify values that may be outside of the project data quality objectives.

Manure

Duplicate manure samples were collected at least once each year and analyzed for percent solids, ammonia, and total nitrogen. See Appendix Table K.1 for results.

The range of relative standard deviations for ammonium in duplicate manure samples was 0.08 to 30.4% with a mean of 8.0%. The project data quality objective relative standard deviation of 7% established in Carey (2004) was met on 4 out of 6 occasions.

The range of relative standard deviation for duplicates of manure total N samples was 2.57 to 18.9% with a mean of 8.0%. The target relative standard deviation of 7% was met on 3 out of 5 occasions. Manure results for the dates that did not meet the target precision are qualified in the results (Appendix L).

Grass crop

Duplicate grass samples were collected each time the field was harvested from July 17, 2005 through October 21, 2008. (See Appendix Table K.2) Individual samples were collected for the three harvests prior to July 17, 2005.

Eighty-three percent of wet weight RSD values were within the 10% target (Appendix Table K.3). Eighty-nine percent of the dry weight values and all of the crude protein values were within the 10% target range. Values outside the target range are qualified in Appendix Table K.2 and in the results (Appendix N). The 10% target for relative standard deviation of grass parameters is particularly stringent.

Soil

Split soil samples were collected quarterly except in 2007, when split samples were not collected. A split sample consisted of a portion of one of the two duplicate samples for a given date. The split samples were analyzed by Soiltest Farm Consultants in Moses Lake, Washington.

The RSDs for 14 split soil nitrate samples are shown in Appendix Table K.4. The mean RSD was 8.3%, slightly above the target of 7% (Carey, 2004).

Results for duplicate soil nitrate samples are shown in Appendix Table K.5. The mean RSD for 107 duplicates was 13.1%. Thirty-nine percent of the relative standard deviations for duplicate soil nitrate samples met the 7% target precision.

The target precision for soil nitrate may have been unreasonably low. The average RSD for 13 soil nitrate studies at dairy farms conducted by Washington State University was 16% (Bary, 2010). The range in soil nitrate concentration values for most of these studies was less than that in the current study.

Because the target precision for soil nitrate was so much lower than the average RSD in similar studies, and the range of soil nitrate values in the study was so wide, a more realistic threshold for acceptability for precision is 20%.

Soil nitrate duplicate samples with relative standard deviations less than 20% are considered acceptable for use without qualification (Andy Bary, 2012). Twenty-four of 107 soil nitrate duplicate samples exceeded the 20% threshold for relative standard deviation and are qualified in Appendix Table K.5 and in the results (Appendix O).

Groundwater

Field quality assurance

All groundwater field meters were calibrated at the start of each day according to the manufacturer's instructions. Replicate field measurements were collected at one monitoring well

for each sampling event to assess overall precision of field and lab results (including the environmental variability over a few minutes between samples). The suite of parameters for the replicate well were all collected for the sample, and the process was repeated for the replicate. Replicate samples were submitted blind to the laboratory.

The relative percent difference (RPD) for field parameters excluding DO was: 0.6-1.4 % (Appendix Table K.6.). The RSD for DO, which was often in the 0-3 mg/L range, was 8.7% (Appendix Table K.7).

On six occasions in 2008, a blank sample of de-ionized water from MEL was collected using the same silastic tubing for the peristaltic pump that had been used for sampling the monitoring wells. Results of blank samples were used to evaluate potential cross-contamination between sample locations from the silastic tubing. Most of the blank results for the nitrogen series were below detection (Table K.8). On May 6, 2008 and June 19, 2008, both nitrate-N and TPN were detected at concentrations roughly 1% of sample values. These results indicate that using the same silastic tubing when purging and sampling each well (one new piece of silastic tubing each sampling event) was not a significant cross-contamination source.

Mean RPDs for laboratory analytes based on field replicates ranged between 2.2 and 5.3%, excluding total dissolved phosphorus (including nitrate-N, TPN, ortho-phosphorus, chloride, dissolved organic carbon, and total dissolved solids). See Appendix Table K.7. The mean RPD for total phosphorus was 17%. The RPD values represent combined field and laboratory precision. The target precision for nutrients, 7%, and that for chloride and DOC, 10%, were met in most cases. Total dissolved phosphorus is the only analyte that did not meet the target precision.

Laboratory quality assurance

Laboratory quality assurance consisted of duplicate blanks, duplicate samples, spiked samples and check (control) standards. MEL conducted internal quality assurance reviews. Most of the results are considered acceptable for use without qualification. Some data were qualified as described in Appendix Tables K.6 through K.8 and shown in Appendix S.

Results

Nitrogen and chloride inputs

Nitrogen inputs—manure and inorganic fertilizer

Manure made up the bulk of the total nitrogen applied to the field during the study (Figure 16). The timing and quantity of total nitrogen applied as manure (as both organic N and ammonia N) and as inorganic fertilizer are shown, by event, on Figure 17 (Plate 2). Inorganic fertilizer was only applied two times, once in 2006 and once in 2007 (31 and 48 lb/acre respectively). Atmospheric input was assumed to be 36 lb/acre (Zebarth et al, 1998).

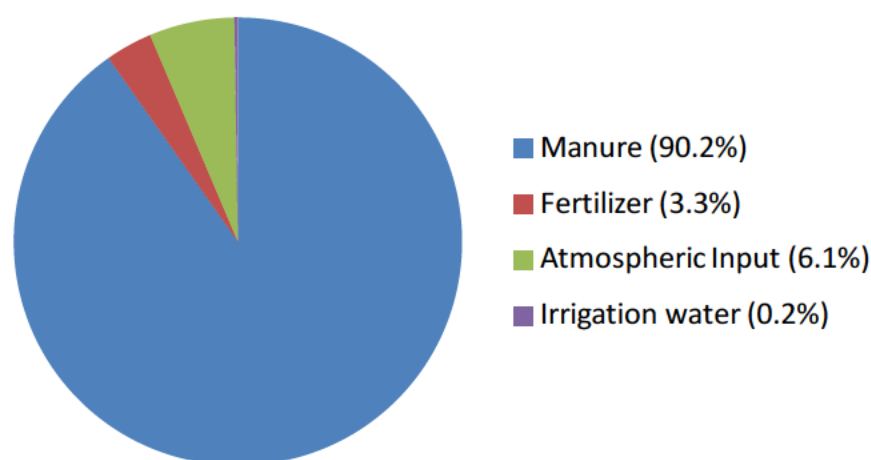


Figure 16. Measured nitrogen inputs by source for 2005 through 2008.

Manure was first applied each year in the spring. The earliest initial application was on February 18, 2005; the latest on April 27, 2006. The earliest final applications for the year occurred on August 31, 2005 and the latest on October 5, 2006. Manure monitoring results are shown in tabular form in Appendix Table L.1.

The annual amount of total nitrogen applied by the producer to the field ranged from 396 to 716 lb/acre with a mean of 548 lb/acre (Figure 18, Plate 2). Between 2005 and 2008, the average nitrogen composition of the applied manure was 47% ammonia N and 53% organic N. The percentage of ammonia was highest in 2005 (67%) and lowest in 2007 (36%). Nitrate was not measured in manure, because it is typically not a significant component (Beegle et al, 2008).

Most of the nitrogen was applied during the growing season, when there was little if any surplus water and uptake by the crop was high. However, depending on the year, between 14 to 25% of nitrogen was applied between October and March (90 to 170 lb/acre/year), when groundwater recharge increases, and crop uptake is lower.

The average nitrogen content in manure, 15 lb/1,000 gallons, was in the high range compared with manure from 25 Whatcom County dairies with similar solids content (3.5%) reported by Sullivan, et al (1994). (See Appendix Table L.2.) The regression developed for the Sullivan et al (1994) data indicated a total nitrogen content of 10.1 to 12.3 lb/1,000 gallons for manure with 3 to 4% solids. Solids and nitrogen content in manure vary depending on the type of treatment system used prior to field application. Dairies with flush systems, second stage lagoons, and mechanical solids separators typically have lower solids content. However, this dairy did not have these systems.

Nitrogen inputs--irrigation water

Annual irrigation totals ranged from 2.5 to 5.7 inches of water (~66,000 to 155,000 gallons/acre) as shown in Table 4.

Table 2. Schedule of irrigation water applied.

Year	Number of Irrigation Events	1st Application Date	1st Application Amount (Inches/acre)	2nd Application Date	2nd Application Amount (Inches/acre)	3rd Application Date	3rd Application Amount (Inches/acre)	Total (Inches/acre)
2005 ¹	2	9/15/2005	1.25	10/15/2005	1.25			2.50
2006	2	7/22/2006	1.75	8/22/2006	3.94			5.69
2007	3	7/17/2007	1.96	8/23/2007	1.95	9/12/2007	1.52	5.43
2008	2	7/8/2008	1.95	8/16/2008	2.46			4.41

¹Dates and amounts are estimates.

Nitrate-N concentrations were measured each year in irrigation water (Figure 19, Plate 2). Ammonium and total persulfate nitrogen concentrations were analyzed in 2007 and 2008 but not in 2005 and 2006. Because the same source of water was used in 2005 and 2006, and nitrate-N concentrations were similar in all years, we assumed that the average total nitrogen concentration for 2007 and 2008, 1.3 mg/L, was also representative of 2005 and 2006 (Appendix Table M.1). The total annual nitrogen input from irrigation, 0.8 to 1.8 lb/acre/year, was roughly 0.2% of the total nitrogen applied (Appendix Table M.2).

Chloride inputs

The amount of chloride applied for each manure application is shown in Figure 19 (Plate 2). Chloride in irrigation water and inorganic fertilizer was not measured and are assumed to be negligible (Appendix Table L.2. for data). The average rate of chloride application to the field in manure was 40 lb/acre/year and was correlated with total nitrogen application ($r^2=0.72$, $n=15$). The annual total amount of chloride applied was 79 to 205 lb/acre (Figure 21, Plate 2).

Nitrogen outputs

Grass crop

The estimated total nitrogen harvested for each event is shown in Figure 22 (Plate 2) and was calculated as:

$$TN = [CP/6.25] \times DM \quad (\text{Equation 1})$$

Where TN= Total Nitrogen (lb/acre)

CP= Crude protein (%)

DM= Dry matter (lb/acre)

(See Appendix N for results of crude protein, dry matter and total nitrogen removed in the crop.)

Figure 23 shows the annual totals of nitrogen harvested. The highest annual total nitrogen yield occurred in 2007 (457 lb/acre), when the total nitrogen applied was 434 lb/acre. The lowest annual nitrogen uptake, 393 lb/acre occurred in 2008, the year with the highest amount of nitrogen applied (736 lb/acre).

The estimate for 2005 nitrogen harvested includes results for the last grass crop of the year, which was not actually removed from the field due to inclement weather. This unrealized harvest was included to represent the grass removal for the year even though it was not removed from the field.

Nitrogen residual

Soil nitrate

Soil nitrate results are shown in Figure 24 (Plate 2, data in Appendix Table O.1). The range of soil nitrate concentrations for weekly intensive monitoring (August through November) was 5.5 to 60 mg/kg. Equation 2 is used to convert soil nitrate concentrations to soil nitrate mass:

$$N = C_{\text{Soil } N} \times 3.5 \quad (\text{Equation 2})$$

Where

N = Soil nitrate concentration (lb/acre)

$C_{\text{Soil } N}$ = Soil nitrate concentration (mg/kg)

A conversion factor of 3.5 assumes dry soil weighs 3.5 million pounds per acre-foot of soil (Sullivan and Cogger, 2003). The range for soil nitrate mass residual at the site was therefore 19 to 210 lb/acre. Current guidance indicates that when fall soil nitrate levels are below 55 lb/acre (15 mg/kg) for grass, no management changes are recommended (Sullivan and Cogger, 2003).

The green shaded areas in Figure 24 represent the recommended period (September through October) for post-harvest soil nitrate sampling (Sullivan and Cogger, 2003). The maximum concentrations during the September to October period ranged from 89 to 150 lb/acre (25.3 to

43.0 mg/kg), or 1.7 to 2.9 times the fall soil nitrate target for grass. The total range of soil nitrate concentrations during the September to October period was 11.5 to 43 mg/kg (40 to 150 lb/acre). The highest value observed, 210 lb/acre (60.0 mg/kg) was outside of the normal sampling period on November 8, 2006.

There was wide variability observed in the soil nitrate concentrations, depending on the particular day the sample was collected. There was typically a two-fold difference between the maximum and minimum weekly soil nitrate concentrations in the fall season each year (September through October), or up to 84 lb/acre (24 mg/kg). Temperature, precipitation, and other factors influence these changes.

Soil temperature and soil moisture

Soil temperatures ranged between -5.0° and 29.9 °C (Figure 25, Plate 2). (See Appendix Table O.1. for tabular data). The 5 highest soil temperature measurements occurred in 2006, mostly in the late summer and fall.

Soil moisture measurements ranged from 12.7 to 54.7%. The lowest soil moisture values occurred in the summers of 2005 and 2006. Below a soil moisture level of 20% of dry weight, grass crops commonly go dormant resulting in little nitrogen uptake (Van Wieringen and Harrison, 2009).

Soil temperature and soil moisture tended to be inversely related. When soil temperature was high in the summer, soil moisture tended to be low due to evapotranspiration. Heavy precipitation and low evapotranspiration in the winter kept the soil moist and cool.

Onsite soil moisture results early in the study indicated that irrigation applied before the roots became dry could prevent the grass from going dormant in late summer. Therefore the first application of water occurred earlier in the season each consecutive year in order to maintain grass growth during the dry late summer.

Soil organic matter and soil chemistry

Results for annual soil organic matter and soil chemistry sampling are shown in Appendix Table O.2. Soil organic matter ranged from 7.0 to 8.4%. The amount of organic nitrogen available for crops is typically calculated at 20 lbs/acre/year for each 1% organic matter up to a total of 120 lb/acre (NRCS, 1998 and Clark, 2012). The organic matter values measured in the study field indicate that the maximum organic N availability value applies to the site. The cation exchange capacity of the soil ranged from 19 to 23 meq/100g.

Groundwater

Aquifer properties

Grain size distribution

Split-spoon soil samples from monitoring well borings were analyzed for grain size distribution. Grain size analyses were used to classify soil samples according to ASTM Method 247-92 (ASTM, 1994). Table 3 lists the values for effective grain size (d_{10}), uniformity coefficient (C_u), and coefficient of curvature (C_c). These values were calculated using particle size distribution curves, and were used to classify soils. Soil classification results are shown in cross-section in Figure 26 (Plate 1). See Appendix P for particle size distribution curves.

The effective grain size, d_{10} , is used here to qualitatively compare the potential rate of leaching and the potential for denitrification. The d_{10} represents the sieve diameter through which only the smallest 10% of the particles pass. The lower the d_{10} value, the larger the portion of fine-grained material in the sample. Slow percolation of liquid through fine-grained material allows for bacterial or chemical processes that use up oxygen and enhance denitrification potential if there is a sufficient electron source such as organic carbon.

The uppermost sediments varied among fine-grained classifications of clay or silt with sand and sand with silt and clay. At side-by-side borings, AKG725 and AKG726, samples from 7.5 to 25 feet BGS contained little silt or clay and were categorized as well graded sand. Samples below 7.5 feet in the other wells had varying amounts fine-grained material. But samples from all wells indicated more rapid movement of water vertically and horizontally below 7.5 feet than at shallower depths. The deepest sample was collected from the top of the confining layer that forms the base of the aquifer at 40 feet (AKG726).

Table 3. Particle size distributions for split spoon soil samples collected during installation of monitoring wells.

Well	Depth (feet BGS)	Soil Class ¹	Description	d ₁₀ (mm) ²	C _u ³	C _c ⁴	D ₆₀	D ₁₀	D ₃₀
AKG-721	2.5	SM or SC	Sand with silt or clay	<.075	166.7	4.8	0.500	0.003	0.085
AKG-721	5.0	ML w/ sand, or CL w/ sand	Silt or clay with sand	<.001					
AKG-721	10.0	SW-SM or SW-SC	Well graded sand with silt or clay	0.078	3.2	1.3	0.270	0.085	0.170
AKG-7222	5.0	SW-SM or SW-SC	Well graded sand with silt or clay	0.122	2.0	2.3	0.240	0.122	0.260
AKG-7222	10.0	SW-SM or SW-SC	Well graded sand with silt or clay	0.115	2.4	0.9	0.280	0.115	0.170
AKG-723	2.5	CL or ML w/ sand, or CL-ML w/ sand	Clay or silt with sand or Silty clay with sand	<.001					
AKG-723	10.0	SP-SM or SP-SC	Poorly graded sand with silt or clay	0.087	4.4	2.2	0.380	0.087	0.270
AKG-724	7.5	SP	Poorly graded sand	0.169	4.4	1.4	0.750	0.169	0.420
AKG-725	2.5	CL or ML w/ sand, or CL-ML w/ sand	Clay or silt with sand or Silty clay with sand	<.075					
AKG-725	7.5	SW	Well graded sand	0.096	2.7	1.2	0.260	0.096	0.170
AKG-726	15.0	SW	Well graded sand	0.139	1.7	2.0	0.230	0.139	0.250
AKG-726	25.0	SW	Well graded sand	0.109	2.8	1.2	0.300	0.109	0.200
AKG-726	40.0	CL or ML w/ sand, or CL-ML w/ sand	Clay or silt with sand or Silty clay with sand	<0.0013					
AKG-727	2.5	SM or SC	Sand with silt or clay	<0.0013	120.8	15.5	0.145	0.001	0.052
AKG-727	10.0	SW-SM or SW-SC	Well graded sand with silt or clay	0.087	3.2	1.3	0.260	0.082	0.165

¹: Plasticity index and liquid limit were not determined, therefore silt and clay could not be distinguished.

²: Effective grain size: Particle size diameter through which 10% of sample particles pass on cumulative particle size distribution curve.

³: C_u: D₆₀/D₁₀ (Coefficient of Uniformity --if 1-3, then well graded, greater than 3 poorly graded).

⁴: C_c: (D₃₀)² / (D₁₀ x D₆₀) (Coefficient of curvature measures the shape of the particle size curve indicating gradation)

Hydraulic conductivity

The Bradbury and Rothschild (1985) method was used to estimate hydraulic conductivity (K), a measure of the permeability of the aquifer (See Appendix Q for details). Hydraulic conductivity is used to estimate the velocity of groundwater flow.

Specific capacity results and estimated K_H 's for 3 on-site monitoring wells are shown in Table 4. Two of the wells (AKG725 and AKG726) are only 3 feet apart but are screened at different depth intervals. Monitoring wells AKG725 and AKG723 are screened from 6 to 13 feet BGS; AKG726 from 25 to 35 feet BGS.

Table 4. Horizontal hydraulic conductivity (K_H) estimates based on specific capacity. (Bradbury and Rothschild, 1985).

Well I.D.	Static water level (feet)	Pumping water level (feet)	Saturated screen length (feet)	Storage coefficient	Aquifer thickness (feet)	K_H (feet/sec)	K_H (feet/day)
AKG726	8.77	8.98	10.0	0.20	35	7.95E-04	69
AKG725	8.72	8.78	4.3	0.20	35	6.07E-04	53
AKG723	7.98	8.06	4.7	0.20	35	4.17E-04	36

K_H : Horizontal hydraulic conductivity (rate of flow through a material over time at a unit gradient).

Groundwater elevations, depth to water, direction and gradient

Groundwater elevations

Hydrographs of water level elevations are shown in Figure 27 (Plate 3). The highest water levels occurred in the winter (December through March); the lowest in the fall (September through October). (See Appendix Table R.1 for data in tabular form.) On January 10 to 11, 2006, monitoring wells AKG722 and AKG727 were submerged and could not be monitored. Subsequent water quality and water level data did not indicate leakage from surface water to the well screen.

Depth to water

Depth to water from the top of the casing in the monitoring wells ranged from 0 to 11.4 feet (Figure 28, Plate 3). (See Appendix Table R.2 for tabular data.) The shallowest water table values (0 to 5.2 feet BGS) occurred in winter months, coincident with the period of highest potential for nitrate leaching and the lowest potential for crop uptake of nutrients (December through March). The deepest annual water table depths, 10.4 to 11.4 feet, usually occurred in October.

The annual range of depth-to-water measurements in individual wells between highest and lowest depths was 4.5 to 10.1 feet/year. The mean annual difference between high and low water table depths was 7 feet.

Groundwater flow direction

Water level contours typical for high (March 2007) and low (June 2006 and October 2007) water table conditions are shown in Figures 29 (Plate 3). The groundwater flow direction was generally southward toward the Nooksack River. During the high water table season (December through March), flow was more southeasterly away from Bertrand Creek suggesting that Bertrand Creek surface water was recharging the aquifer. During the low water table season (June through October), flow was more southerly, parallel to the creek and toward the Nooksack River.

Hydraulic gradient

The horizontal hydraulic gradient (i_H), or slope of the water table, was calculated as the difference between the water table elevations (dh) of the two wells farthest apart in the direction of flow (AKG723 and AKG727) divided by the distance between the wells (dl), 925 feet as shown in Equation 3.

$$i_H = \left(\frac{dh}{dl} \right) = \frac{[WT_{AKG727} - WT_{AKG723}]}{925 \text{ feet}} \quad (\text{Equation 3})$$

Where

WT_{AKG727} = Water table elevation at AKG727 (feet)

WT_{AKG723} = Water table elevation at AKG723 (feet)

The horizontal gradient ranged from 0.0004 to 0.0036, with a mean of 0.002 (S.D.=0.0006, $n=24$). Hydraulic gradients tended to be lowest in the late summer to fall season and highest during the winter.

The vertical hydraulic gradient (i_V) was calculated as the difference in water table elevation (dh) of the two side-by-side monitoring wells (AKG725 and AKG726) of different depth divided by the vertical distance between the midpoints of the well screens (dl) as shown in Equation 4.

$$i_V = \left(\frac{dh}{dl} \right) = \frac{[WT_{AKG725} - WT_{AKG726}]}{23.6 \text{ feet}} \quad (\text{Equation 4})$$

Positive vertical hydraulic gradients for the side-by-side shallow (13 feet deep) and deep (38 feet deep) wells, AKG725 and AKG726, indicate a downward hydraulic potential throughout the study period (Figure 30, Plate 3). An increasingly positive trend in the vertical hydraulic gradient value over the study period indicates that water and dissolved constituents moved downward more quickly over time. The mean vertical hydraulic gradient was 0.0047 (S.D.=0.001, $n=43$).

Groundwater flow velocity

The average horizontal velocity of groundwater flow was estimated using a variation of Darcy's Law:

$$v = \frac{-K_H \left(\frac{dh}{dl} \right)}{n_e} \quad (\text{Equation 5})$$

where,

v = Average linear velocity (feet/day)

K_H = Horizontal hydraulic conductivity (feet/day)

dh/dl = Horizontal hydraulic gradient (dimensionless)

n_e = Effective porosity (ratio of the volume of interconnected voids/volume of material)

We used the K_H value for AKG725 (Table 4), because it is in the middle of the field and probably most representative of the shallow water table at the site. The seasonal range of horizontal hydraulic gradient was used for dh/dl .

The range of velocity estimates was 0.04 to 0.76 feet/day, or 15 to 277 feet/year, with a mean value of 0.47 foot/day, or 172 feet/year (Table 5).

Table 5. Estimates of groundwater velocity at the study site.

Hydraulic Conductivity (K_H) ¹ (feet/day)	Hydraulic Gradient (feet/feet)	Effective Porosity ²	Velocity (feet/day)
53	0.0004	0.25	0.14
53	0.0022	0.25	0.47
53	0.0036	0.25	0.76

¹: From AKG725 in Table 4.

² n_e : Effective porosity: Ratio of the void space through which flow can occur to the total volume of material.

Recharge

Fall recharge

The total amount of recharge that occurs at the study site between the late fall and early winter (a key period of leaching of surplus nitrate remaining in the soil column after the growing season) was estimated for each year using Equation 6 (Healy and Cook, 2002).

$$R_{\text{Fall}} = S_y \times (WL_2 - WL_1) \quad (\text{Equation 6})$$

where

R_{Fall} = Fall recharge (feet),

S_y = Specific yield,
 WL_2 = Highest water level for the winter (feet)
 WL_1 = Lowest water level for the fall (feet)

We used the average difference in water table elevation in the six shallow wells between the lowest level each year (usually October) to the highest level (usually December). We used a specific yield of 0.25. The resulting fall recharge estimates for the fall period ranged from 0.98 to 2.08 feet (Table 6).

Table 6. Fall recharge estimates at the study site.

Average change in water table height in the fall (October through December) (feet)					Specific yield	Estimaed Recharge (feet)				
2004	2005	2006	2007	2008		2004	2005	2006	2007	2008
6.43	8.32	6.78	5.66	3.90	0.25	1.61	2.08	1.70	1.42	0.98

Spring recharge

Most of the focus on nitrate loss to groundwater is on the fall/early winter season, however recharge and associated leaching probably continues to occur in late winter/early spring when precipitation exceeds evapotranspiration (Chesnaux and Allen, 2007b).

Because evapotranspiration can significantly affect water table elevations in the spring, Equation 1 is not valid for estimating spring recharge. An alternative method for estimating the maximum monthly recharge potential in the spring is to calculate the amount of “surplus water” generated during this period, using Equation 7. The surplus water value for each year is estimated for the period of January through March.

$$R_{Spring\ Max} = S = P - E \quad \text{Equation 7}$$

Where

$R_{Spring\ Max}$ = maximum spring recharge potential (feet)

S = Surplus water (feet)

P = Precipitation at the study site (feet) (January through March)

E = Evapotranspiration (feet) (January through March)

Evapotranspiration data reported daily at Abbotsford, British Columbia Airport, 6 miles northeast of the site, were used for surplus water estimates (Table 7). These data are assumed to be representative of the study site, because temperature and crop uptake are very similar.

Table 7. Monthly evapotranspiration in inches at Abbotsford, B.C. Airport from www.farmwest.com.

	2004	2005	2006	2007	2008	2009
January	0.59	0.63	0.63	0.71	0.55	0.63
February	1.10	1.34	0.91	0.87	1.02	0.98
March	2.01	1.93	1.85	1.65	1.61	1.30
Totals	3.70	3.90	3.39	3.23	3.19	2.91

Surplus water estimates are shown in Figure 31 for January through March of 2004 through 2008. (Data in Appendix Table T. 2). The total annual spring surplus water (January through March) ranged from 0.64 to 1.15 feet.

Surplus water either leaches to groundwater, is channeled to surface water via tile drains (not present at the study site), or flows off-site as surface runoff. Since not all surplus water necessarily reaches the water table, the calculated surplus water value is an estimate of the maximum potential recharge at the site. Because the topography at the study site is flat and rain events are relatively moderate, it is reasonable to assume that most of the surplus water fact leaches to the water table unless the land is flooded (Cox and Kahle, 1999).

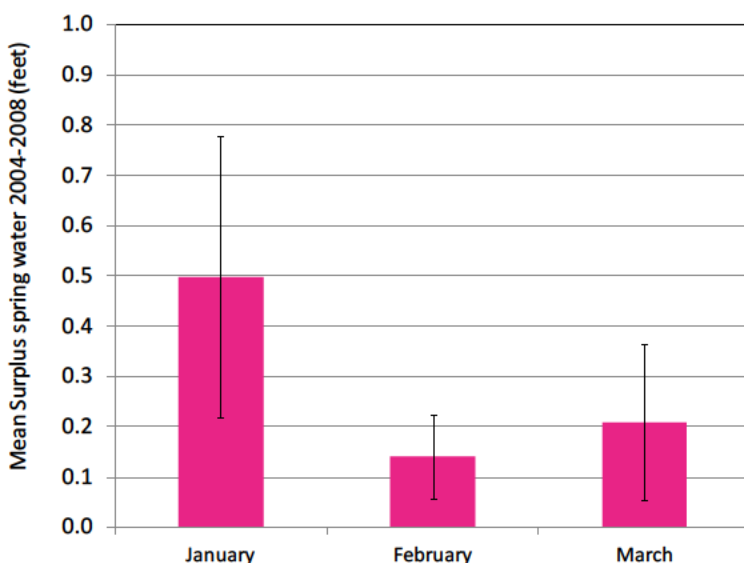


Figure 31. Mean monthly water surplus (precipitation at the site minus evapotranspiration at Abbotsford, B.C. Airport in 2004 to 2008).

Error bars represent one standard deviation of the mean.

Temperature

Daily average air temperature are in Appendix Table T.3—(large--needs to be zipped).

Groundwater quality

Time series results for groundwater quality samples at the study site are shown in Plates 4, 5, and 6. Results are shown for pH, dissolved oxygen, conductivity, nitrate-N, chloride, organic carbon, total dissolved solids, and total phosphorus. Total N concentrations were very similar to nitrate-N and are not shown graphically. See Appendix Table S.1 for monitoring well groundwater quality data in tabular form. Table S.2. summarizes results from upgradient private wells.

pH

pH affects the oxidation/reduction state of ammonia in groundwater. When pH is below 8, most of the ammonia is in the ammonium form (NH_4^+). This is the case in most of western Washington ground- and surface waters. pH also affects the rate of bacterial conversions of ammonia to nitrate (nitrification) and nitrate to nitrogen gas (denitrification) (Buss, et al, 2004 and 2005 and Coyne, 2008). (See “Nitrogen Cycle” above.)

Results for groundwater pH shown in Figure 32 (Plate 4) are all below 8, indicating that ammonium is the predominant form of ammonia in groundwater at the study site. pH values ranged from 5.1 to 6.0 in all monitoring wells except AKG724 and AKG 726 and did not vary seasonally. The lowest pH values occurred in well AKG724, where values were consistently below 5.0. The highest pH occurred in the deep well, AKG726, with values typically around 6.5. Both nitrification and denitrification rates would tend to be lower in groundwater at AKG724 than at the other wells.

Dissolved oxygen

Results for dissolved oxygen (DO) are shown in Figure 33 (Plate 4). The DO concentration has a major influence on the potential for denitrification to occur as well as the oxidation state of nitrogen and phosphorus in water. When the DO concentration is less than 1 to 2 mg/L and organic carbon (or other electron donor) is in sufficient supply, bacteria convert nitrate to nitrogen gas (Buss et al., 2005, Bates and Spalding, 1998).

DO concentrations were consistently above 2 mg/L in wells AKG721 and AKG725 in the northwest part of the field. Most measurements in these wells were in the range of 6 to 10 mg/L, far above the level where denitrification occurs. In the other shallow monitoring wells, DO concentrations followed a seasonal pattern, with oxygen decreasing during the late summer, sometimes below 2 mg/L, probably due to high bacterial activity.

In the winter, DO concentrations were rapidly replenished with oxygen-rich recharge from precipitation. The highest DO concentrations in most wells occurred in January and February following a water table rise of up to 7 feet within several weeks. Monitoring wells on the east side of the site followed this pattern most closely (e.g., AKG722).

DO concentrations in the deep well, AKG726 and the upgradient wells were consistently at or close to 0.0 mg/L (anoxic). Observations above 0.2 mg/L in AKG726 were not made using the standard sealed flow cell, because it was unavailable. Instead purge water was directed into the bottom of a 5-gallon bucket with the DO probe also at the bottom. The higher values are probably an artifact of measuring in an open container.

Specific conductance and total dissolved solids

Specific conductance and total dissolved solids results (Figure 34 and 35, Plate 4) followed similar trends throughout the study. Both parameters generally increased in the fall-winter of 2004 to 2005, declined slightly, and peaked again in summer 2005. During the following 3 years

both parameters gradually declined until December 2008, when three of the shallow wells showed substantial increases.

All conductivity and TDS results were below the secondary maximum contaminant levels for drinking water, 700 umhos/cm for conductivity and 500 mg/L for TDS (Chapter 246-290 WAC).

Chloride

Chloride concentrations are shown in Figure 36 (Plate 5) and ranged from 4.4 to 30.6 mg/L with the highest concentrations in 2004 and 2005. All results were below the secondary maximum contaminant levels for drinking water of 250 mg/L (Chapter 246-290 WAC).

Patterns observed in chloride concentrations were similar to those observed for specific conductance and TDS. Concentrations of chloride were initially higher in the shallow well, AKG725, located beside the deep well, AKG726, than in the deep well. Like most of the shallow wells in the study, chloride decreased at AKG725 for the first 3 years of the study until late 2008. Occasional increases in chloride at AKG725 corresponded with manure applications followed by heavy precipitation. A particularly large increase in chloride occurred at AKG725 in August 16, 2005, when chloride reached 30 mg/L. Chloride decreased in the deep well, AKG726, during the study but only slightly compared with the shallow wells. Upgradient well chloride ranged from 16.0 to 17.8 mg/L.

Dissolved organic carbon

Organic carbon results are shown in Figure 37 (Plate 5). All organic carbon data collected before February 5, 2005 represent total organic carbon (no filtering). Samples collected on February 5, 2005 and afterward were filtered in the field and represent dissolved organic carbon except those from AKG726. Samples from AKG726 were not filtered and represent total organic carbon, because the in-line filtering system was not equipped for the submersible pump needed for the deeper well.

AKG722 consistently had the highest dissolved carbon (DOC) concentrations with seasonal fluctuations that mimicked the water table elevations with about one month lag time (Figure 38). The maximum DOC observed was 9.6 mg/L at AKG722 on February 27, 2008. The other shallow wells sometimes fluctuated with the water table elevation but to a lesser extent than at AKG722.

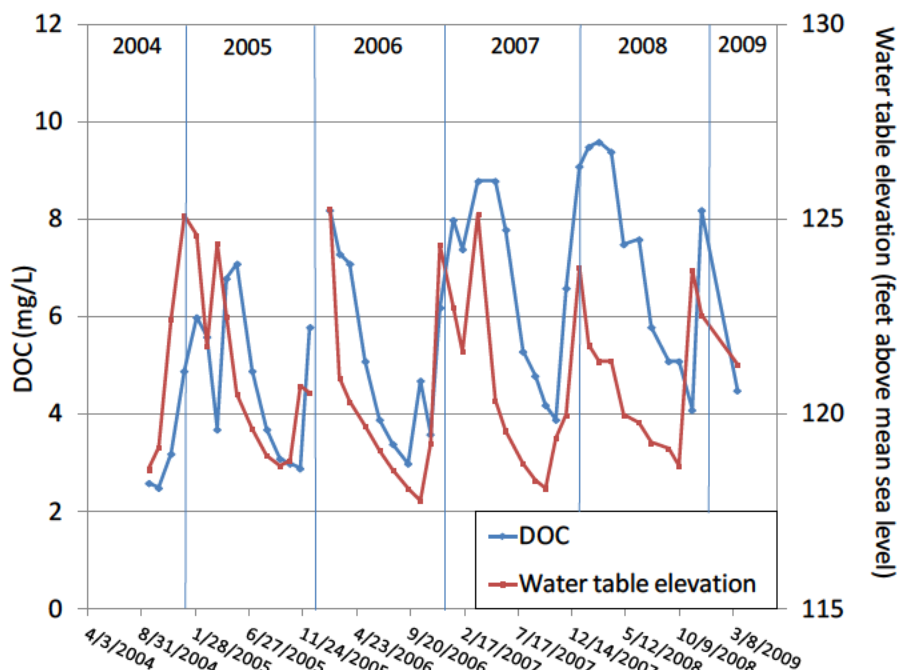


Figure 38. DOC concentrations and water level elevations in monitoring well AKG722.

Nitrate-N

Nitrate-N concentrations are shown in Figure 39 (Plate 5). Nitrogen was predominantly in the nitrate form in all wells except the deep, mostly anoxic well, AKG726, where nitrate was virtually absent, and ammonium was the dominant nitrogen species.

Concentrations of nitrate-N in shallow groundwater were well above 10 mg/L at the beginning of the study, except at AKG722. During the winter months of 2004-2005, nitrate-N concentrations increased in all wells to the highest levels observed during the study. The concentration at AKG722, 45 mg/L, was more than four times the MCL for drinking water.

During the second and third years of the study, 2006-2007, nitrate-N concentrations in the shallow wells decreased at about the same rate as declines in chloride concentration. Within the general decline, nitrate-N fluctuated somewhat. During the last few months of the study, December 2008 through March 2009, nitrate-N increased substantially in four out of six shallow wells, one reaching 20 mg/L (AKG725). Chloride followed a similar pattern.

In the anoxic deep well, AKG726, nitrate-N concentrations ranged from below the detection limit of 0.01 mg/L to 0.333 mg/L.

Concentrations of TPN were very similar to nitrate-N in shallow monitoring wells, indicating little organic nitrogen present.

Unfiltered nitrate concentrations in the upgradient wells screened at 29 to 33 feet were 0.014 to 0.021 mg/L.

Ammonium

Results for ammonium are shown in Figure 40. Ammonium is typically attenuated in the soil, because positively charged ammonium ions (NH_4^+) adhere to negatively charged soil particles (Buss, 2004). Because the pH was less than 6 in the shallow monitoring wells and below 7 in the deep well, almost all of the ammonia is in the ammonium form. Therefore we will refer only to ammonium-N in the rest of the report.

Ammonium concentrations in the shallow groundwater were below the detection limit of 0.01 mg/L on 37 out of 46 dates. The highest number of detections occurred on October 18 to 19, 2004, when the range of concentrations in 6 wells was 0.012 to 0.018 mg/L. Ammonium was the main nitrogen species found in samples from the deep well, AKG726, with concentrations ranging from less than 0.170 to 0.248 mg/L. Ammonium in the upgradient wells was 0.194 to 0.255 mg/L.

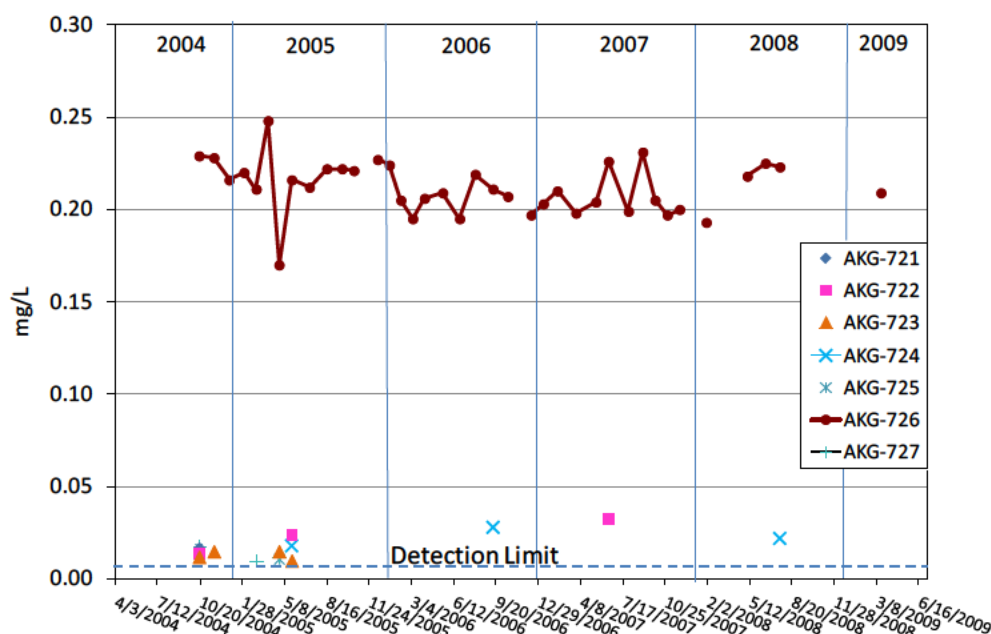


Figure 40. Ammonium-N results in monitoring wells.

Total persulfate nitrogen

Total persulfate nitrogen concentrations were very similar to nitrate-N and are listed in Appendix Table S.1.

Total dissolved phosphorus

Because it was not the main focus of the study, total dissolved phosphorus (TDP) concentrations were only monitored from 2004 through 2006. Samples from AKG726 were not filtered and therefore represent total phosphorus (TP).

Results for phosphorus in groundwater are shown in Figures 41 (Plate 5). Shallow groundwater TDP was ranged from 0.0005 to 0.0129 mg/L. Results for TP in the deeper anoxic groundwater were somewhat higher (0.113 to 0.264 mg/L).

Discussion

The study results are discussed below from the perspective of nitrate movement, groundwater quality and aquifer characteristics. Manure, soil, and crop results are used to interpret groundwater results. Findings from the study site are also compared with other parts of the aquifer to determine how representative the study findings are in comparison to the SBA as a whole. See VanWieringen and Harrison (2009) for a detailed interpretation of manure, soil, and crop results.

The discussion will focus on the following aspects of the results and their influence on nitrate at the study site:

- Vadose zone and aquifer properties
- Groundwater and soil quality
- Management and environmental effects
- Soil nitrate as an indicator of leaching to groundwater
- Annual nitrogen cycles
- Estimates of groundwater nitrate from leaching

Vadose zone and aquifer properties

The Abbotsford Sumas Aquifer, of which the SBA is a part, is not totally homogeneous. Grain size, depth to water, and aquifer thickness vary spatially. These characteristics can play an important role in the vulnerability of different portions of the SBA to nitrogen leaching. Properties of the vadose zone and aquifer at the study site are discussed below and compared with information from other parts of the aquifer.

Grain size distribution

Movement of water and solutes, including nitrate, to the water table and along the groundwater flowpath are affected by the texture of the substrate. Water penetrates more slowly through finer materials, which can lead to higher surface runoff in the winter. Finer soils over the central and western parts of the SBA tend to become saturated in the winter due to lower infiltration capacities and flat topography. Recharge water percolating to the water table is rich in oxygen. During the summer, when recharge is limited, oxygen becomes depleted by bacterial consumption in the finer soils, and denitrification is more likely. Slower velocity in fine-grained materials also allows more time for bacterial degradation and oxygen consumption than in coarser materials.

Denitrification is less likely in coarser, well-drained soils and aquifer material, where there is more space between particles, recharge is higher, infiltration rates are faster, and replenishment of oxygen exceeds oxygen consumption by microorganisms. Paul and Zebarth (1997) found that denitrification accounted for only 17% of annual nitrogen loss from medium to coarse soils in south-coastal British Columbia following dairy manure application. The remaining 83% of soil nitrate was presumed to leach to groundwater.

NRCS (1996) suggests 15 to 35% denitrification loss in somewhat poorly drained soils like those overlying the study site, where soil organic matter is greater than 5%. (The percent soil organic matter ranged from 7.0 to 8.4% at the site.)

In addition to lower denitrification rates, coarse soils and underlying materials also have been found to have higher manure nitrogen mineralization rates than those in fine-textured materials. This allows ammonium to be converted more quickly to nitrate and, if not taken up by a crop, can result in rapid nitrate leaching to groundwater (Van Es et al, 2006 and Magdoff, 1978). Likewise Ruijter et al (2007) found consistently higher groundwater nitrate concentrations in coarse-grained materials than in fine-grained materials at 34 farms studied in the Netherlands.

Figure 42 (Plate 1) compares the effective grain size results from the study boring to the locations shown on Figure 43 (Plate 1). Samples from the 5-foot to 30-foot depths tend to grade coarser from west to east, with the Abbotsford samples having ten times higher effective grain size values at 16 and 26 feet than the other sites. The Abbotsford samples indicate much coarser material in the northeastern part of the SBA than found to the west and southwest.

This pattern suggests that nitrate losses due to denitrification are probably higher at the study site than is typical of the SBA, and especially higher than the very coarse-grained eastern side of the aquifer.

Hydraulic conductivity

Hydraulic conductivity estimates for the study site, 36 to 69 feet/day, were lower than 84% of wells in the SBA analyzed by Cox and Kahle (1999). Based on specific capacity data from drillers' logs for 170 wells, Cox and Kahle (1999) estimated a median of 270 feet/day for K_H . The location of the study site at the edge of the outwash aquifer probably makes groundwater less vulnerable to contamination by leaching than most of the SBA due to the area's fine-grained material and higher potential for denitrification.

Moisture content and preferential flow

Permeability of vadose zone materials is a function of moisture content. The hydraulic conductivity of unsaturated material is typically one-half to one-fourth that of saturated materials (Bouwer, 1995). Most of the unused nitrate below a field is therefore transported downward during the high precipitation period (October through March) when vadose zone material is most saturated.

Preferential flow paths, cracks and holes in the vadose zone also can have a major influence on the timing and amount of liquid transport to groundwater. These alterations of the substrate allow for very rapid flow of water and dissolved constituents, like nitrate, below the surface, preventing crop uptake or other processes that might remove nitrate or alter the chemistry of the water.

Depth to water

Shallow groundwater depth, like that observed during this study, provides for a short transport route for nitrate and dissolved constituents to groundwater unless the percolating water is redirected via tile drains to a surface water body. Tile drains are not present in the study field but are common in much of the low-lying area overlying the SBA. The winter water table at the study site was typically within 0 to 4 feet of the surface, intersecting the root zone of the crop and resulting in direct dissolution of nitrate into groundwater.

In fine-grained settings with low infiltration rates, a high water table can result in more nitrogen loading directed to surface water (via runoff and tile drains) and less percolation to groundwater. Surface water in the SBA eventually discharges to marine water, where eutrophication is typically limited by nitrogen (Howarth and Marino, 2006).

Nitrate leaching in areas of the SBA with greater depths to water and coarser material than the study site would probably have less dampening of nitrate leaching from denitrification and surface runoff and therefore may be more vulnerable to overapplication of nutrients.

Groundwater flow

After entering the aquifer, water and solutes at the site move mainly horizontally and in a southerly direction below the study site. The average groundwater flow velocity for the site, 0.47 foot/day is an order of magnitude lower than the average value for the Abbotsford-Sumas Aquifer reported by Cox and Kahle (1999) of 2 feet/day. Groundwater movement in most of the SBA is therefore much quicker than at the study site.

Because nitrate entering the groundwater at the study site moves more slowly than in most of the aquifer, and there is at least some loss of nitrate to denitrification, this site may not be as susceptible to contamination as parts of the aquifer where materials are coarser, groundwater moves more quickly and there is no loss of nitrate to denitrification.

Annual nitrogen cycles

To help characterize the impact of nitrogen application on underlying groundwater conditions, we conducted a mass balance analysis of the annual growing season nitrogen cycle. The mass balance method assumes that the total amount of nitrogen inputs minus the total amount of nitrogen outputs yields the amount of nitrogen left over at the end of the season. This amount of nitrogen remaining at the end of the growing season (residual or excess) provides an estimate of the nitrogen that is potentially available to leach to the water table (Harter and Matthews, 2005; Zebarth, 1998). The method assumes that measurements of inputs and outputs are complete and that there are no unidentified gains, losses or storage in the system.

Nitrogen mass balance analysis

The difference between annual inputs and outputs of nitrogen provides an estimate of the excess nitrogen remaining at the end of each growing season (Equation 8):

$$N_{\text{Excess}} = N_{\text{Input}} - N_{\text{Output}} \quad \text{Equation 8}$$

where: N_{Excess} = Nitrogen mass left in the soil column at the end of the growing season (lb/acre)

N_{Input} = Nitrogen inputs during the growing season = $M + F + S + A + I$ (lb/acre)

N_{Output} = Nitrogen outputs during the growing season = $Y + V + D$ (lb/acre)

where:

M= Nitrogen applied in manure (lb/acre)

F = Nitrogen applied as inorganic fertilizer (lb/acre)

S = Nitrogen mineralized from soil organic matter (lb/acre)

A= Nitrogen from atmospheric deposition (lb/acre)

I = Nitrogen applied in irrigation water (lb/acre)

Y= Nitrogen removed in crop (lb/acre) (measured)

V = Nitrogen lost to volatilization during application (lb/acre)

D = Nitrogen lost to denitrification (lb/acre)

The above equation assumes that the system is in a steady state, with no gains or losses unaccounted for. This is probably most valid for the crop after 3 to 5 years of growth (Chang, 2006).

The components of Equation 8 that were measured during the study include manure, inorganic fertilizer, irrigation water, and crop removal. The components that were not measured during the study (soil organic matter, atmospheric deposition, volatilization, and denitrification) were estimated based on the following assumptions:

- 15 % of the total nitrogen applied was lost to ammonia volatilization (NRCS, 2006; Clark, 2012)
- 15% of the total nitrogen applied was lost to denitrification (NRCS, 2006; Clark, 2012).
- Nitrogen mineralized from soil organic matter was assumed to be 120 lb nitrate-N/acre/year for a field with 6% or greater organic matter (Clark, 2012).
- Atmospheric input of nitrogen was assumed to be similar to Abbotsford Aquifer, 36 lb/acre/year (Zebarth et al, 1998).²

Table 8 shows the major annual growing season inputs (N_{Input}) and outputs (N_{Output}) of nitrogen to the study field and the resulting end of season excess of nitrogen (N_{Excess}). The mass balances for nitrogen inputs and outputs for each growing season during the study are shown graphically in Figure 44 (Plate 6) and 45.

² Current rates may be higher (Bittman, 2012).

Table 8. Mass balance estimates of annual end of growing season excess nitrogen (lb/acre).

	2005 ¹	2006	2007	2008
INPUTS (N_{Input})				
Manure total N applied (M)	644	363	386	715
Inorganic Fertilizer (F)	0	31	48	
Irrigation water (I)	0.8	1.8	1.7	1.4
Mineralized soil organic N (S) ²	120	120	120	120
Atmospheric input (A) ³	36	36	36	36
N_{Input} totals	801	552	591	872
OUTPUTS (N_{Output})				
Crop N removed (Y)	439	430	457	393
Ammonia volatilized (15% of applied N) (V)	97	54	58	107
N denitrified (15% of applied N) (D)	97	54	58	107
N_{Output} totals	632	539	573	608
$N_{Excess} = (N_{Input} - N_{Output})$	168	13	19	265

¹ Last grass cutting is included in crop removal but was not actually removed from the field due to wet weather.

² NRCS (2006); Clark (2012).

³ Zebbarth et al (1998)

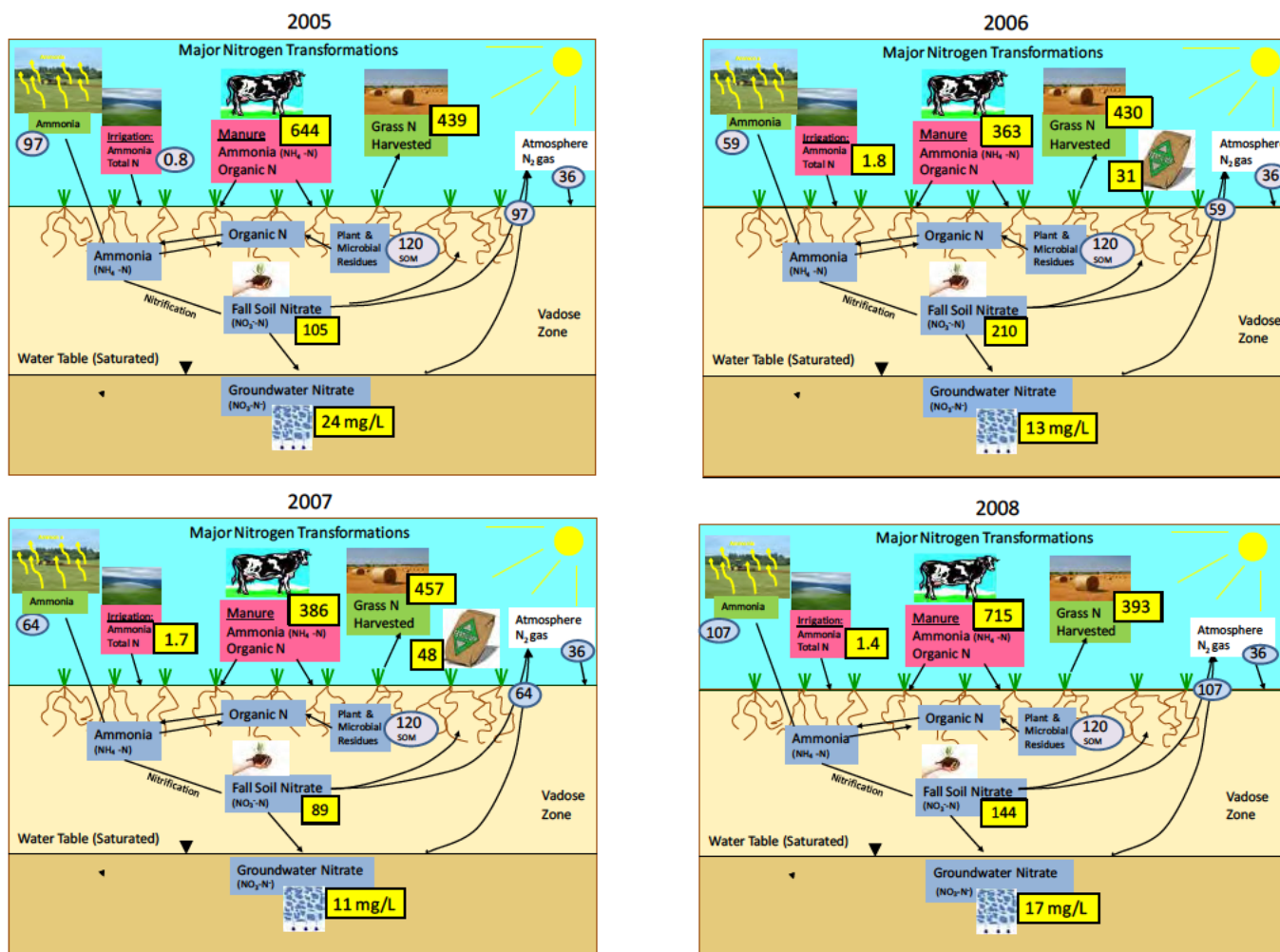


Figure 45. Annual nitrogen inputs, outputs, and residual at the study site.

Inputs, outputs and soil nitrate are in lb/acre. Values in yellow boxes are measured values (means of duplicate values in most cases; maximum for soil nitrate). Values in blue ovals are estimates. Groundwater nitrate-N concentrations are mean winter (November to December) values at AKG725 in mg/L. Atmospheric input is from Zebarth et. al (1998). Fall soil nitrate residual is the maximum of weekly values for September through November. Denitrification and ammonia outputs are each assumed to be 15% of manure total N. SOM is the estimated nitrogen input from soil organic matter. Color code: green=outputs, pink=inputs, white=inputs and outputs, blue= resulting effects on soil and groundwater.

Comparison of growing season excess nitrogen to groundwater concentrations

Monitoring well AKG725 was chosen to most clearly represent the maximum effect of surplus nitrogen on groundwater. Groundwater samples in this mid-field well were consistently well oxygenated, precluding loss to denitrification that probably occurred in groundwater and soil adjacent to 4 of the other shallow wells. Monitoring well AKG725 is also further from potential upgradient influences. The November to December groundwater nitrate concentrations were used, because effects from the immediately preceding growing season's activities were most apparent in shallow groundwater in the early winter.

Figure 46 compares the annual end-of-season excess nitrogen estimated by the mass balance analysis to the corresponding mean winter groundwater nitrate concentration at monitoring well AKG725.

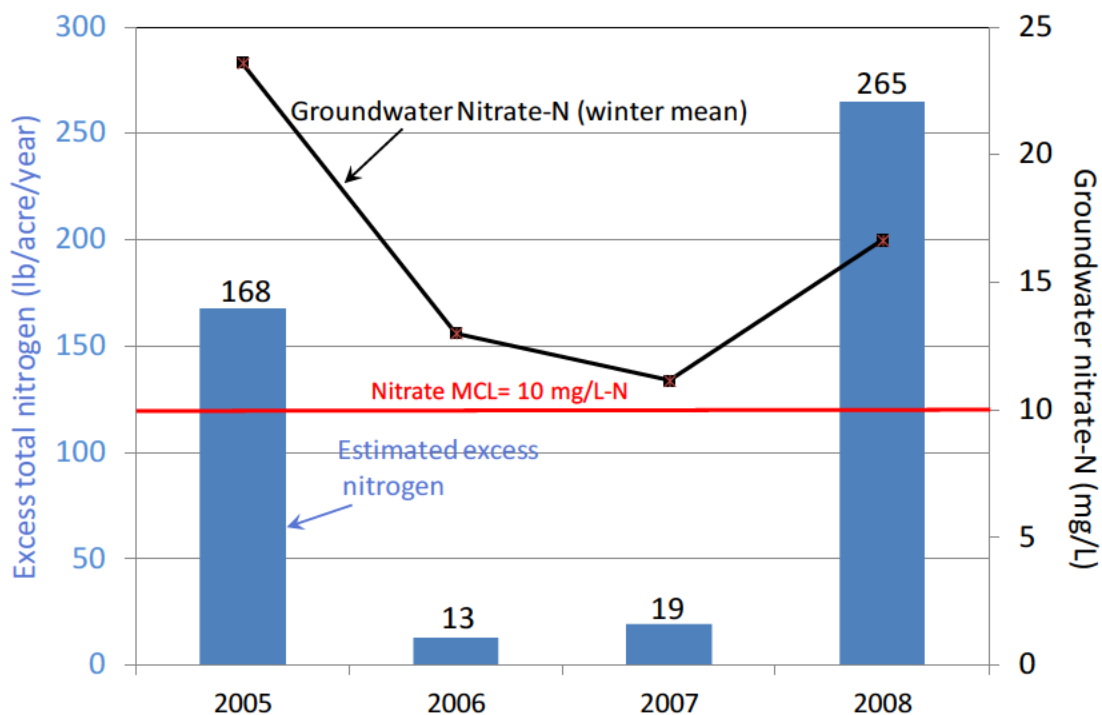


Figure 46. Annual total nitrogen in excess of that taken up by the crop (N_{Excess}) and mean winter (November and December) nitrate-N concentration in well AKG725.

Large total excess nitrogen values were observed in 2005 and 2008, while the nitrogen applied in 2006 and 2007 was in significantly better balance. Figure 46 illustrates that mean winter groundwater nitrate concentrations showed a pattern that paralleled the mass balance results. Winter groundwater nitrate concentrations were closer to the MCL in 2006 and 2007, 11 to 13 mg/L, when (N_{Excess}) was lower.

Groundwater and soil quality

Background

The groundwater monitoring design is based on the assumption that the most recently recharged water transports soluble constituents to the water table and is most representative of current management practices. The most recently recharged water is at the top of the water table, especially during periods when recharge occurs (October through March).

Because of the position of their open intervals (29 to 33 feet below ground surface), the groundwater quality results reported for the upgradient domestic wells in the Results chapter above best represent the upgradient condition of the *lower* portion of the unconfined aquifer. The groundwater quality values from these wells are not considered representative of the *shallow* background condition at the far northern (upgradient) end of the study field.

A shallow background well was not installed for the study. However, it is unlikely that upgradient groundwater conditions on properties north of the study area had a significant effect on the groundwater quality results collected during the study period for the following reasons:

- The average lateral velocity of groundwater flow in the study area was 0.47 feet/day (~172 feet/year). Using this value, groundwater immediately north of the northern study field boundary would take an estimated 3.5 years to reach the mid-field monitoring wells (AKG725, Figure 5), a time frame well after the majority of the project sampling had occurred. It would take approximately 6.2 years to reach the southernmost monitoring wells (AKG723), a time frame well past the final date of sampling. Even if groundwater immediately north of the study field had an elevated nitrate concentration, and traveled conservatively with groundwater without further attenuation, it would have little or no effect on the nitrate results for 4 out of the 6 monitoring wells for the majority of the study.
- A 3.7-acre residence lies immediately upgradient of the study site. The potential upper-range nitrogen input from the on-site sewage system at the residence was 36 lb nitrogen/year (9 lb nitrogen/person/year times 4 residents living in the house full time—U.S. EPA, 2002) and potentially ~85 lb nitrogen/acre for lawn care on 2 acres (170 lb nitrogen total). The total estimated annual nitrogen loading to 3.7 acres would therefore be 206 lb nitrogen/3.7 acres or 56 lb nitrogen/acre. This is roughly 8 to 14% of the amount of nitrogen applied to the study field between 2005 and 2008. This suggests that the water quality impact on the study monitoring wells from these upgradient land uses are relatively insignificant in comparison to the study field manure loading.
- The property further upgradient of the residence was cultivated during the study and probably received manure at a rate similar to those observed at the study field. However, it takes ~2.8 years for groundwater at the downgradient edge of this field (324 feet from the upgradient edge of the study field) to reach AKG721, 5.3 years to reach AKG725 and 8.0 years to reach AKG723.
- Due to the overall downward vertical hydraulic gradient observed throughout the study period, groundwater present at a distance from the site monitoring wells would have a tendency to move downward as it traveled. As observed earlier, monitoring wells screened at

the water table are most likely to be capturing water more recently recharged from above. The very short vertical transport distances between the study field surface and the water table (0 to 11 feet) indicates the water quality results from these shallow wells represent direct impacts from surface activities, with limited influence from laterally upgradient groundwater.

On the basis of the evidence above, the groundwater quality results discussed below are assumed to accurately represent water quality responses to manure loading and management occurring on the surface of the study field.

Management and environmental effects

The groundwater and soil nitrate portions of the nitrogen cycle measured during the study were affected by a variety of environmental and farm management factors that interact in complex ways. The main factors affecting groundwater and soil quality included:

- Nitrogen application rate
- Timing of manure application
- Temperature
- Soil moisture
- Precipitation
- Denitrification
- Tillage

In this section we compare various lines of evidence for the combined effects of management and environmental influences on soil and groundwater nitrate.

Nitrogen application rate

The amount of nitrogen applied to the ground (from the combination of manure, fertilizer applied, and mineralized soil organic nitrogen) has a significant effect on the amount of nitrogen available for leaching to groundwater. In general, the more nitrogen added to a field during the growing season in excess of the crop uptake and removal, the higher the amount of nitrate reaching the water table.

Some leaching of nitrate is unavoidable when growing a crop. The maximum practical crop uptake efficiency for nitrogen is about 80% of the amount applied according to the U.S. EPA Advisory Board (2011). However, this efficiency level is rarely attained even when using best management practices, and a lower uptake efficiency is more realistic. In the San Joaquin Valley of California, where flood irrigation (border check and furrow) is the main irrigation method, 60% uptake efficiency is used as a standard for nutrient management (Dzurella et al, 2012; California Regional Water Quality Control Board Central Valley Region, 2007). A major influence on the efficiency level possible for this region is that flood irrigation leaches a substantial portion of nitrate (Harter et al, 2006).

The estimated mass balance excess nitrogen applied to the field in 2005 and 2008 (168 to 265 lb/acre) was 9 to 20 times higher than the excess estimated during 2006 and 2007, when the excess applied was 13 to 19 lb/acre respectively (Figure 44, Plate 6). Although data were not

available for nitrogen application to the field in 2004, high fall soil nitrate concentrations in 2004 (up to 180 lb/acre in August) indicate a large residual of nitrate was also available for leaching during the fall and winter of 2004 to 2005 (Figure 24, Plate 2). The highest groundwater nitrate concentration observed, 43 mg/L-N, occurred on December 28, 2004 following tillage of the field and heavy seasonal precipitation.

Tillage of the field in April of 2004, before the study began, probably led to mineralization of a substantial amount of nitrogen from accumulated soil organic nitrogen not included in N_{Excess} estimates and will be discussed below. However, a comparison of chloride and nitrate concentrations in groundwater indicate a decrease in excess nitrate and chloride loading from the beginning of the study until late 2007 unrelated to tillage (Figure 46, Plate 6).

Like nitrate, chloride is a conservative element that does not adsorb to soil particles and is associated with manure application (Rodvang, et al, 2004). Manure is the only major source of chloride in the area, and chloride in the soil from manure would not be affected by tillage (Cogger, 2013). The significant decrease in both nitrate and chloride during the first 3 years (Figure 46) indicates that the decreasing amount of excess manure applied to the field (Figure 44) was probably the main factor contributing to improved groundwater nitrate through 2007.

Timing of manure applications

Timing of manure application had an effect on nitrate loss to groundwater. Manure applied just prior to major precipitation events at rates that resulted in excess soil nitrate were often followed first by higher soil nitrate values and then by higher shallow groundwater nitrate concentrations. However, when manure was applied during dry periods and in amounts that the crop could take up, no subsequent increase in soil or shallow groundwater nitrate was observed.

Examples of manure timing effects in spring and fall are described below.

Spring applications

Spring application of manure (February through May) can cause distinct spikes in underlying groundwater nitrate concentrations if a large amount of precipitation occurs after the application(s). Because precipitation exceeds evapotranspiration during the February through March period (Figure 29a) and nitrogen mineralization occurs during this time (Trindade et al, 2001), the amount of manure applied and the timing of spring application over the Sumas-Blaine Aquifer require extreme caution from a groundwater protection standpoint. Applying manure before the crop can efficiently take up nitrogen in the earliest days of the growing season risks leaching substantial nitrate to groundwater.

In the spring of 2005, although conditions were dry for several days before and after both spring manure applications, the total amount of nitrogen applied, 272 lb/acre, combined with nitrate mineralizing from soil organic matter, appears to have exceeded the new grass crop's uptake potential. Groundwater nitrate concentrations increased in all shallow monitoring wells by 4 to 13 mg/L-N during the following 1 to 3 months (Plate 7).

Wet weather in March and April 2005 (8.6 inches of rain in the month following the February application) contributed to downward water and nitrate movement as indicated by the 2.5-foot rise in the water table, to within 2.4 feet of the ground surface at AKG722 (Figure 28, Plate 3). When the water table is so close to the surface, most nitrate in the soil that might have been available for crop uptake is probably lost to groundwater when the water table recedes.

In the spring of 2007, although the amount of manure nitrogen applied, 240 lb/acre, was similar to that applied in spring 2005, a smaller and less immediate increase in groundwater nitrate was observed at three wells (AKG721, AKG723, and AKG727) (Plate 7). Nitrate concentrations in these wells increased by 2 to 5 mg/L following the 2007 spring manure applications.

Groundwater nitrate increases were either not present or were less obvious following spring manure applications in 2006 and 2008 (Plate 7). A smaller amount of nitrogen applied in spring 2006 (171 lb/acre) than in 2005 and 2007 and lower surplus water in late April (Appendix Table T.2) probably resulted in less nitrate leaching in 2007. Low amounts of excess water in spring of 2008 apparently prevented or delayed leaching of nitrate to groundwater.

Lack of dry conditions in the spring likewise can delay initial manure application and crop harvest throughout the growing season. In 2006, the first grass cutting occurred on April 2 followed by the first manure application on April 27, 6 to 10 weeks later than in previous years. The time available for the repeated process of manure application, crop uptake and crop removal was shortened by several weeks.

Fall applications

In most of the temperate northern hemisphere, application of manure in the fall, even on perennial crops, presents a high risk of nitrate leaching (Kowalenko, 1987; Zebarth, 1998). Crop growth slows in the fall, precipitation increases, and leaching of nitrate is all but assured.

The risk of applying manure too late in the fall was demonstrated at the study area on the graphs on Plate 8. For example, a late (October) final fall manure application in one year of the study, 2006, resulted in significant increases in groundwater nitrate in the weeks following the application. In 2007, however, when the last application was applied earlier in the season (September), no significant increases in groundwater nitrate were observed. In 2006, the late manure application led to an average increase in nitrate concentration of 6 mg/L-N in the shallow winter groundwater (maximum 16 mg/L-N). In late 2007, nitrate actually decreased in 5 out of 6 shallow wells, by an average of 2.4 mg/L (Figure 39, Plate 5).

Most of the variables for nutrient uptake and application were similar in 2006 and 2007. Excess nitrogen, growing degree days, and crop removal were similar, although weather and crop removal were slightly better in 2007 (Figures 44, 47, and 48-- Plate 6). This suggests that the key difference between these two years was the late timing of the final manure application.

2006-- Impacts from late final fall manure application

Although the amount of nitrogen applied in the fall of 2006, 90 lb/acre, was the second lowest fall manure application during the study, the late timing on October 5 and pre-existing high soil

nitrate level led to significant effects on shallow groundwater nitrate concentration in subsequent months.

By November 8, 2006, the soil nitrate concentration increased from 31 mg/kg (107 lb/acre) on October 1 to 60 mg/kg (210 lb/acre), 4 times the recommended level for nutrient balance and well beyond the growing season (Figure 49, Plate 6). A 4.7-inch rain event in early November provided the recharge necessary to transport the nitrate downward, because the soil nitrate concentration at one-foot depth decreased to 15 mg/kg (55 lb/acre) by November 15, 2006.

As the nitrate mass dissolved from the soil and infiltrated downward with the recharge, the water table rose 6.7 feet (Figure 28, Plate 3), and the mean shallow groundwater nitrate-N concentration increased by 7.6 mg/L to 14.7 mg/L. Individual well nitrate concentrations increased by up to 16 mg/L-N (Plate 8). Chloride increased at the same time in individual wells, verifying manure as the source of the nitrate increase (Plate 8).

Prolonged precipitation in the fall can also prevent crop harvest. In 2005, 102 lb/acre of nitrogen in the grass crop were not removed from the field due to wet weather. In such cases the full effect of crop uptake is not realized, because some of the crop nitrogen that would have been removed decays and may be available for leaching to groundwater.

2007--Favorable effects of early final manure application

In 2007, the last manure application for the year (September 7) occurred one month earlier than in 2006 (Figure 16, Plate 2). Early application of manure and the lightest fall application during the study, 77 lb/acre, apparently allowed for crop uptake of nutrients before temperatures decreased substantially and before the onset of heavy rain. As a result, groundwater nitrate concentrations did not spike in the fall of 2007 as they did in 2006 (Plate 8). Nitrate concentrations in 4 out of 6 wells remained below 10 mg/L-N through February 2008.

These examples indicate that timing of manure applications during the periods at the margins of the major growing season (fall and early spring) pose a high risk of nitrate leaching due to the combination of unpredictable influencing factors. Precipitation, especially heavy rain, during these times can transport nitrate from recent manure applications below the root zone before crop uptake can occur.

Conditions during the late winter/early spring are particularly conducive to rapid leaching of available nitrate to the water table. Ammonium from manure applied during this high surplus water time eventually nitrifies to nitrate, while at the same time organic nitrogen remaining in the soil begins to mineralize to nitrate. Nitrate from both sources (winter/early spring manure application and mineralized organic matter) is susceptible to leaching before the grass crop can take up the bulk of the load (Trindade et al, 2001; Zhao et al, 2010).

Temperature

Crop growth and nitrogen uptake increase with warmer temperatures leaving, less excess nitrogen in the soil at the end of the growing season. VanWieringen and Harrison (2009) evaluated the influence of temperature on crop removal during the study using three methods that

estimated growing degree units (Gus). All three methods indicated that 2008 was significantly cooler than the other three years and that most of the year-to-year variation in grass yield was due to temperature.

The Griffith and Thompson (1996) method used by VanWieringen and Harrison (2009) for estimating GDUs appears to best fit the study location and crop and is shown in Equation 8.

$$\text{GDU} = [(T_{\text{Max}} + T_{\text{Min}})/2] - 32 \quad \text{Equation 8}$$

Where

GDU = Monthly Growing Degree Units (F°)

T_{Max} = Maximum monthly temperature (F°)

T_{Min} = Minimum monthly temperature (F°)

The annual GDU totals for January through October are shown in Figure 47 (Plate 6). The highest year for thermal input to the grass crop, 2007, coincided with the highest crop nitrogen uptake, one of the lowest excess nitrogen values (Figures 44 and 47, Plate 6), and groundwater nitrate values fluctuating around 10 mg/L (Figure 39, Plate 5). Likewise the year with the lowest annual GDU total, 2008, coincided with the lowest crop nitrogen removal. The lower crop removal in 2008 and higher excess nitrogen resulted in a return to shallow groundwater nitrate concentrations above 10 mg/L-N in most wells.

Soil moisture

During the growing season, insufficient soil moisture inhibits crop growth. When crop growth is inhibited, less nitrogen will be taken up by the crop, leading to an excess of nitrogen in the soil that could leach to groundwater. In the summers of 2005 and 2006, soil moisture declined to levels that restrict grass growth and bacterial mineralization of ammonia and organic nitrogen (i.e. less than 20%). During this time, the grass crop probably went dormant resulting in lower nitrogen uptake, lower yield, and more excess nitrogen than if more moisture had been available (VanWieringen, 2009) (Figure 25, Plate 2).

To prevent crop dormancy and improve crop uptake of nitrogen, the producer began irrigating in July 2007. Soil nitrate concentrations were lower and crop uptake higher in 2007 than in 2006 following the earlier start of irrigation (Figure 24, Plate 2).

While the additional moisture resulted in higher rates of crop uptake of nitrogen, too much irrigation water during cool, wet periods of the growing season can move some of the excess nitrogen below the root zone, preventing possible crop uptake and contributing to higher winter groundwater nitrate concentrations. This may have occurred in July and/or August 2008, when the growing season was cooler and wetter than normal.

Precipitation and Recharge

Year-to-year variation in recharge from precipitation also probably had an effect on nitrate concentrations in shallow groundwater beneath the field. Recharge generally decreased during the study as did winter groundwater nitrate concentrations (Figure 50). Graham (2013) found that during high recharge years annual shallow nitrate concentrations in the Canadian portion of

the Abbotsford-Sumas Aquifer were roughly 30% higher. These findings are consistent with the fact that recharge is the primary mechanism for downward transport of soil nitrate; the more recharge infiltrating the soil column, the more nitrate will be transported to the water table.

Rozemeijer, et al (2009) found that 55 to 153% of variation in the mean shallow groundwater nitrate concentration beneath an intensively monitored manured field was due to year-to-year variation in the amount of precipitation excess (precipitation minus evapotranspiration). Van Es, et al (2006) likewise found that precipitation had a large influence on the concentration of nitrate leaching beneath manured fields. Oenema et al (2010), Sonneveld et al (2010), Boumans et al (2005) and Bechmann et al (1998) also found that the effectiveness of management practices was affected by weather patterns.

Denitrification

The DO condition in soil and groundwater can have a major effect on groundwater nitrate concentration. When the DO is below 2 mg/L, denitrification can remove nitrate and lead to lower nitrate concentrations in groundwater (Van Es et al, 2006; Rodvang et al, 2004). DO varied spatially and over time in the shallow monitoring wells indicating variability in the amount and timing of denitrification in groundwater at the site.

Denitrification is not as significant in parts of the Sumas-Blaine Aquifer with coarser soils and greater depth to the water table. In a similar study at a manured field east of the study site, DO concentrations were never below 2 mg/L in 6 monitoring wells during 2 years of monthly monitoring (Carey, 2002). Therefore nitrate impacts from manure leaching on groundwater in areas of the aquifer with high DO would probably be more severe than those found in the current study.

Denitrification probably caused routine/periodic nitrate loss in groundwater in 4 of the 6 shallow monitoring wells, when the DO was 2 mg/L and lower (AKG722, AKG723, AKG724, and AKG-726-- Plate 7.) Denitrification probably also occurred above the water table in these areas before leachate reached the water table, which is typical of wet, fine-textured soils (Coyne, 2008; Paul et al, 1997; Murray et. al, 1995). This factor likely muted the effect of excess nitrogen on groundwater sampled from these wells.

Groundwater from the well screened at the bottom of the aquifer, AKG726, was consistently nearly anaerobic and, because of its depth, probably represents a mixture of older water that entered the aquifer from upgradient and/or in previous years from local recharge. Therefore this well was not considered representative of current management practices at the study site (Plate 7).

Nitrate: chloride ratio as indicators of denitrification

Chloride is largely non-reactive in the subsurface, and changes in chloride concentrations in groundwater are assumed to be due to either dilution, or a change in loading. These characteristics make chloride useful for evaluating nitrate changes in groundwater (McCallum et al, 2008 and Rodvang et al, 2004).

An additional tool for evaluating whether denitrification is a major factor in controlling groundwater nitrate concentrations is to compare ratios of nitrate-N to chloride ($\text{NO}_3\text{-N:Cl}$) in groundwater (McCallum, et al, 2008).

Nitrate and chloride consistently followed similar patterns in the two high-DO wells (AKG721 and AKG725; Figure 51, Plate 6). Initially both wells had a higher concentration of nitrate than chloride. But after the first year, nitrate and chloride tracked more closely.

During months with little or no recharge from the surface to groundwater, and when the water table is too far below the root zone for plant uptake (June through September), relative changes in the proportion of nitrate and chloride concentrations are probably due to denitrification rather than crop uptake or management activities.

In the four wells with at least occasionally low DO, nitrate and chloride concentrations generally tracked closely when DO was above the threshold for denitrification (Figure 52, Plate 6). However, when DO fell below 2 mg/L, nitrate-N and chloride concentrations diverged, indicating loss of nitrate to denitrification. For example, in the fall of 2006, when the DO in AKG722, AKG723, AKG724, and AKG727 were below 2 mg/L (Plate 8), chloride concentrations remained at the same level or increased, while nitrate-N concentrations dropped by 4-10 mg/L (Figure 51, Plate 6).

The mean $\text{NO}_3\text{-N:Cl}$ ratios for the two DO conditions were:

- High DO wells (always greater than 2 mg/L): 1.39 (SD=0.26, n=96)
- Low DO wells (less than 2 mg/L at times): 1.05(SD=0.44, n=188)

The $\text{NO}_3\text{-N:Cl}$ ratio was higher and relatively stable in the high-DO wells throughout the study. The higher variation, as indicated by the higher standard deviation in the seasonally low-DO wells is consistent with the fluctuation in DO concentrations above and below the denitrification threshold in these wells.

McCallum, et al (2008) found a similar distinction between $\text{NO}_3\text{-N:Cl}$ ratios in wells beneath manured fields where denitrification was occurring and those where it was not occurring.

Denitrification was probably inhibited at well AKG724, where pH was below 5 most of the time. Inhibition of denitrification occurs below pH 5 (Buss et al, 2005 and Brady and Weil, 2002). The pH at AKG724 ranged from 4.5-5.2. The pH in the other monitoring wells was above 5.

Tillage effects

Tillage of a grass field that has received manure applications for many years often leads to mineralization of accumulated organic nitrogen, resulting in higher loading of nitrate to the underlying groundwater (Oenema et al, 2010; Whitmore et al, 1992).

Plowing and replanting of the field in spring 2004, after the field had been unplowed for several years, was at least partly responsible for a significant input of nitrate to the water table at the beginning of the study (Figure 53, Plate 6). The highest monthly mean shallow groundwater

nitrate-N concentration observed during the study, 30 mg/L, occurred on December 28, 2004, following the water table rise to within 1.3 to 4.1 feet of the surface beneath the field due to fall recharge (Figures 28, Plate 3). The high water table may have allowed groundwater to come in contact with newly mineralized nitrate that had not already leached.

Chloride concentrations in shallow groundwater followed a pattern similar to nitrate during the study and indicate that release of nitrate from soil tillage was not the only reason for high nitrate concentrations in late 2004 and 2005 (Figure 46, Plate 6). Because chloride, like nitrate, is very soluble in water but is not mobilized by tillage, it is likely that elevated chloride levels in shallow groundwater in 2004 and 2005 are the result of higher loading of manure prior to 2005. A combination of 1) nitrate release from the soil due to tillage, 2) excess nitrogen from manure applied to the newly planted field, and 3) high recharge probably led to elevated groundwater concentrations from late 2004 through much of 2005.

Soil nitrate as an indicator of potential groundwater leaching

What does the recommended fall soil nitrate guideline value mean for groundwater?

In order to understand what the residual fall soil nitrate value means for groundwater, it is helpful to consider that 27 lb of nitrogen, when mixed with one acre-foot of water is equivalent to the groundwater MCL of 10 mg/L of nitrate-N. Equation 9 shows the calculation for leachate nitrate based on the amount of nitrogen available for leaching at the end of the growing season and the amount of fall/early winter recharge.

$$L_{\text{NO}_3\text{-N}} = \frac{0.37(N_{\text{Residual}})}{R_{\text{Fall}}} \quad \text{Equation 10}$$

Where

- $L_{\text{NO}_3\text{-N}}$ = Estimated leachate nitrate concentration (mg/L)
- N_{Residual} = Excess nitrogen as maximum fall soil nitrate (lb/acre)
- R_{Fall} = Fall recharge (September through December)(feet)

This method assumes that all of the N_{Residual} mixes with all of the R_{Fall} and is transported to the water table at one time, with no additional nitrate subsequently added. This is a lower-bound assumption, because Graham (2013) noted that with more recharge, more nitrate appeared to reach groundwater. In addition, N_{Residual} is highly variable over a weekly period even when duplicate samples are analyzed.

Equation 10 estimates the leachate concentration during the fall/early winter season. However leaching can occur whenever precipitation exceeds evapotranspiration, and there is nitrate in the soil column. Nitrification can also occur during and after the fall/early winter period, albeit at a lower rate than during the growing season (Zhao et al, 2010). This additional nitrate is also susceptible to leaching.

Table 9 shows the results of combining the estimated R_{Fall} values (Table 2) with the target fall soil nitrate guideline for grass of 55 lbs/acre (Sullivan and Cogger, 2003) using Equation 9. The

calculated leachate nitrate concentrations, 10 to 21 mg/L-N, would exceed the MCL in 4 out of 5 years.

Table 9. Estimated nitrate-N concentration in leachate assuming 55 lb/acre of soil nitrate is mixed with the estimated fall recharge at the study site in the fall of 2004 through 2008.

	2004	2005	2006	2007	2008
Fall recharge (feet)	1.61	2.08	1.70	1.42	0.98
Nitrate concentration in water when 55 lb/acre soil nitrate is mixed with annual fall recharge	13	10	12	14	21

Fall soil nitrate variability and sample timing

Fall soil nitrate concentrations have been used as an indicator of nutrient balance as well as an indicator of the amount of nitrogen likely to leach to groundwater during the imminent winter season. One problem with this method of evaluating residual nitrogen is that the variability in concentration from one week to the next is large. Factors such as timing of manure application, temperature, and the amount and timing of recent precipitation can all affect the concentration of nitrate in the soil in the fall at any given moment in time (Oenema et al, 2010).

A large variation in soil nitrate occurred each year during the fall (Figure 24, Plate 2). The difference between the minimum and maximum weekly fall soil nitrate results collected each year was 47 to 84 lb/acre (14 to 24 mg/kg; Table 10). The large variation in soil nitrate concentrations during the fall illustrates that the collection of a single sample is unlikely to correspond with the true maximum soil nitrate condition. One sample, the current standard for fall soil nitrate sampling, is therefore unlikely to provide an accurate measure of the actual amount of nitrate available for leaching to groundwater.

Table 10. Fall soil nitrate variability and resulting soil nitrate-derived leachate concentrations.

Year	Soil nitrate minimum (mg/kg)	Soil nitrate maximum (mg/kg)	Difference between minimum and maximum soil nitrate (mg/kg)	Minimum estimated leachate nitrate concentration (mg/L-N) ¹	Maximum estimated leachate nitrate concentration (mg/L-N) ¹	Difference between min and max leachate nitrate concentrations (mg/L)
2004	19	43	24	15	35	19
2005	12	30	19	9	24	15
2006	16	29	14	12	23	11
2007	12	25	14	10	20	11
2008	21	41	20	17	33	16

¹ Leachate nitrate estimated using Equation 9 and soil nitrate (mg/kg) x 3.5 = Soil nitrate (lb/acre).

Table 10 also shows the results of combining the estimated R_{Fall} values from Table 2 with the soil nitrate concentrations measured during the fall of each study year, using Equation 9. The annual range in variation between the highest and lowest soil nitrate-derived leachate concentration was 11 to 19 mg/L-N. This further illustrates that soil nitrate results are inherently too variable for predicting the real risk to groundwater.

Reasons for high seasonal variability in fall soil nitrate include combinations of the following:

- Timing of the last manure application (sometimes after the last harvest)
- Timing of the last harvest (which requires a period of dry weather),
- Onset and amount of heavy fall precipitation which varies each year (Sonnevelt, 2010)
- Crop uptake and removal, which depends on complex interactions between temperature, soil moisture, precipitation and irrigation

In most years when the maximum fall soil nitrate concentration substantially exceeded the 55 lb/acre (15 mg/kg) target (2004, 2006 and 2008), winter groundwater nitrate concentrations increased in most, if not all, monitoring wells (Figure 39, Plate 5). In the winter following the lowest maximum fall soil nitrate concentrations, 2007, nitrate decreased in some shallow wells, and increases in other wells were less than in other years.

There are many problems with using post-harvest soil nitrate as a predictor of groundwater nitrate. The fall soil nitrate value can either underestimate or overestimate leaching to groundwater (Viers et al, 2012). However, it is a useful tool for tracking changes and revising nutrient management. The target concentration at which management changes are recommended should, however, be revised to include implications for groundwater quality.

Winter/spring soil nitrate

Several factors operate throughout the late winter/early spring (January through early February) that contribute to the likelihood of nitrate leaching to groundwater distinct from the initial fall flush. These include:

- continued mineralization of organic nitrogen followed by nitrification to nitrate
- ongoing high surplus water due to high precipitation
- limited crop uptake

While mineralization of organic nitrogen is often assumed to be negligible during the cold non-growing months, Trindade et al (2001) found significant soil mineralization and nitrification over the winter (27 to 48% of the annual total mineralized in a dairy field). Zhao et al (2010) found that nitrate mineralized during the winter can contribute substantially to the amount of nitrate available for plant uptake in the spring or for leaching before plants can take it up.

Chesnaux et al (2007) showed that springtime precipitation can lead to substantial recharge carrying nitrate from inorganic fertilizers to the water table in the Abbotsford area a few miles northeast of the study site.

During our study the low frequency of soil nitrate sampling during the non-fall seasons limited our ability to evaluate soil nitrate concentrations as an indicator of winter/spring groundwater impacts. However we found indications that an appreciable amount of soil nitrate was present in two years (2005 and 2008) before the growing season began and before manure was applied (Figure 54). This soil nitrate was available for plant uptake, but also for leaching, because precipitation exceeded evapotranspiration by 0.66 to 0.70 feet during the period from January through March (Table 7), and the water table was close to the surface.

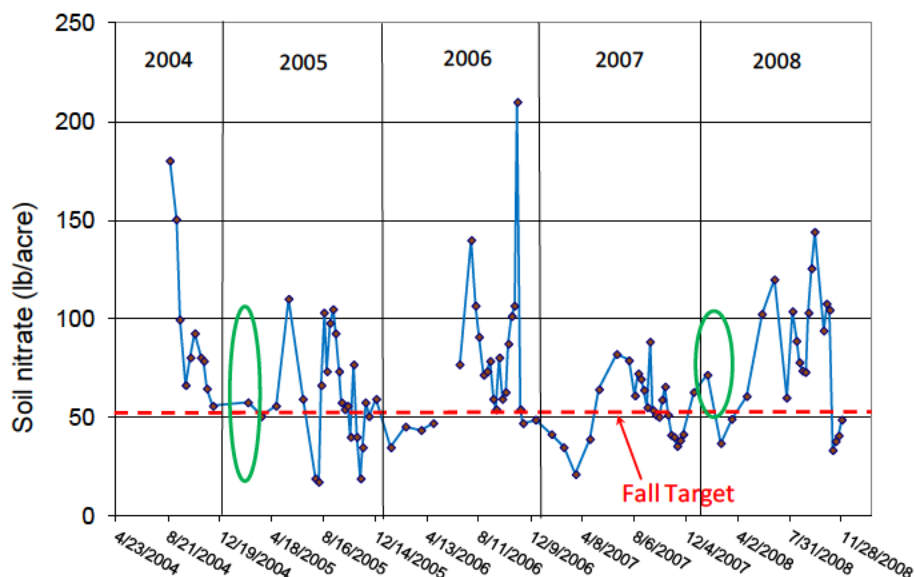


Figure 54. Soil nitrate concentrations with green circles indicate late winter/early spring periods when leaching could impact groundwater before the main growing season.

Table 11 shows the estimated leachate concentrations that would result from the soil nitrate in winter samples from February 22, 2005 and January 22, 2008 mixing with the surplus water available for 30 days beginning the month following the soil sample (Equation 9).

Table 11. Estimated winter leachate nitrate concentration using Equation 9, soil nitrate concentrations and surplus water the month following the soil sample for the recharge (R) term.

Soil Sample Date	Soil Nitrate mg/kg	Soil Nitrate lb/acre	Surplus water in the following calendar month after soil sampling (feet)	Estimated Leachate Nitrate-N (mg/L)
2/22/2005	16.5	58	0.3	72
1/22/2008	20.5	72	0.2	133

With a short travel distance to the water table (roughly 2 to 7 feet) and ongoing recharge events to transport nitrate through the soil column, movement of at least a portion of this high-concentration leachate to groundwater is likely.

We did not quantitatively evaluate the impact of this amount of loading to the groundwater, but nitrate results from several shallow wells showed indications of a nitrate source other than manure during the winters of 2004 to 2005 and 2007 to 2008. Winter (November through February) chloride concentrations decreased or remained stable while nitrate concentrations increased in 3 wells in 2004 to 2005 and 4 wells in 2007 to 2008 (Plate 9).

Since nitrate and chloride typically track closely, and the nitrate and chloride from growing season manure applications had most likely already reached the water table, these nitrate increases in shallow groundwater appear to be from an on-site source, potentially from soil

nitrate that mineralized after the fall. One other possible source for the winter 2004 to 2005 could be lingering effects from the nitrate mobilized by tillage, which also would not be linked with chloride.

Estimating the mass of nitrate left over at the end of the growing season

Two methods were used to develop estimates of the nitrate mass available for leaching at the end of each growing season. One method (A) assumes that the nitrogen mass from the Table 8 N_{Excess} values is completely converted to nitrate mass. This may yield an upper-bound result, because there are many pathways for nitrogen to follow other than nitrate. However, if management practices are fairly consistent over a number of years, and the field is in a relative steady state, the net conversion to nitrate may be equal to the amount of excess nitrogen (Chang, 2006).

The other method (B) uses the maximum annual fall soil nitrate concentration N_{Residual} during the study and assumes that all of the residual is accounted for. This leaves out any nitrate deeper in the soil column. The results for these two methods are summarized in Table 12.

Table 12. Estimates for the mass of nitrate left at the end of the growing season using A) mass balance and B) maximum fall soil nitrate.

Methods for estimating excess nitrate mass (lb/acre)	2004	2005	2006	2007	2008
A) Mass balance (N_{Excess})		168 ¹	13	19	265
B) Maximum fall soil nitrate (N_{Residual}) ²	150	105	210	89	148

¹ Last grass cutting not removed from the field but is included in crop removal.

² September 1 through November 15

Calculating leachate nitrate concentration

We estimated the fall leachate nitrate concentration using the two yearly excess mass terms (A and B) from Table 12 and the estimated volume of fall recharge (Table 9) using Equation 10.

$$L_{\text{Mass}} = \frac{0.37(N_{\text{Mass}})}{R_{\text{Fall}}} \quad \text{Equation 11}$$

Where

L_{Mass} = Estimated leachate nitrate concentration (mg/L)
 R_{Fall} = Fall recharge (September through December)(feet)

Table 13 shows the estimated annual nitrate leachate concentrations. The range of estimated leachate nitrate-N concentrations was 10 to 135 mg/L. Method A yielded a median estimated nitrate-N leachate concentration of 18 mg/L, a value nearly 2 times greater than the MCL and a wide range of 2.8 to 100 mg/L. Method B yielded a median value of 16 mg/L and a range of 12 to 39 mg/L nitrate-N.

Table 13. Annual nitrate-N leachate concentration estimates using two methods for estimating L_{Mass} (mg/L).

	A. Mass Balance	B. Mean Fall Soil Nitrate
2004		26
2005	30	12
2006	2.8	16
2007	5.0	15
2008	100	39

Figure 55 shows compares the leachate concentrations based on Methods A and B with the actual mean winter groundwater nitrate concentration at AKG725. Neither method was a reliable predictor. The mean soil nitrate method predicted a leachate concentration similar to the measured groundwater concentration in 2006 and 2007. The remainder of the years does not show an obvious relationship between **either** predicted leachate nitrate concentration and that in groundwater. While these approaches to estimating nitrate excess may be useful for approximating in-field nutrient balance, they are not reliable for predicting groundwater impacts.

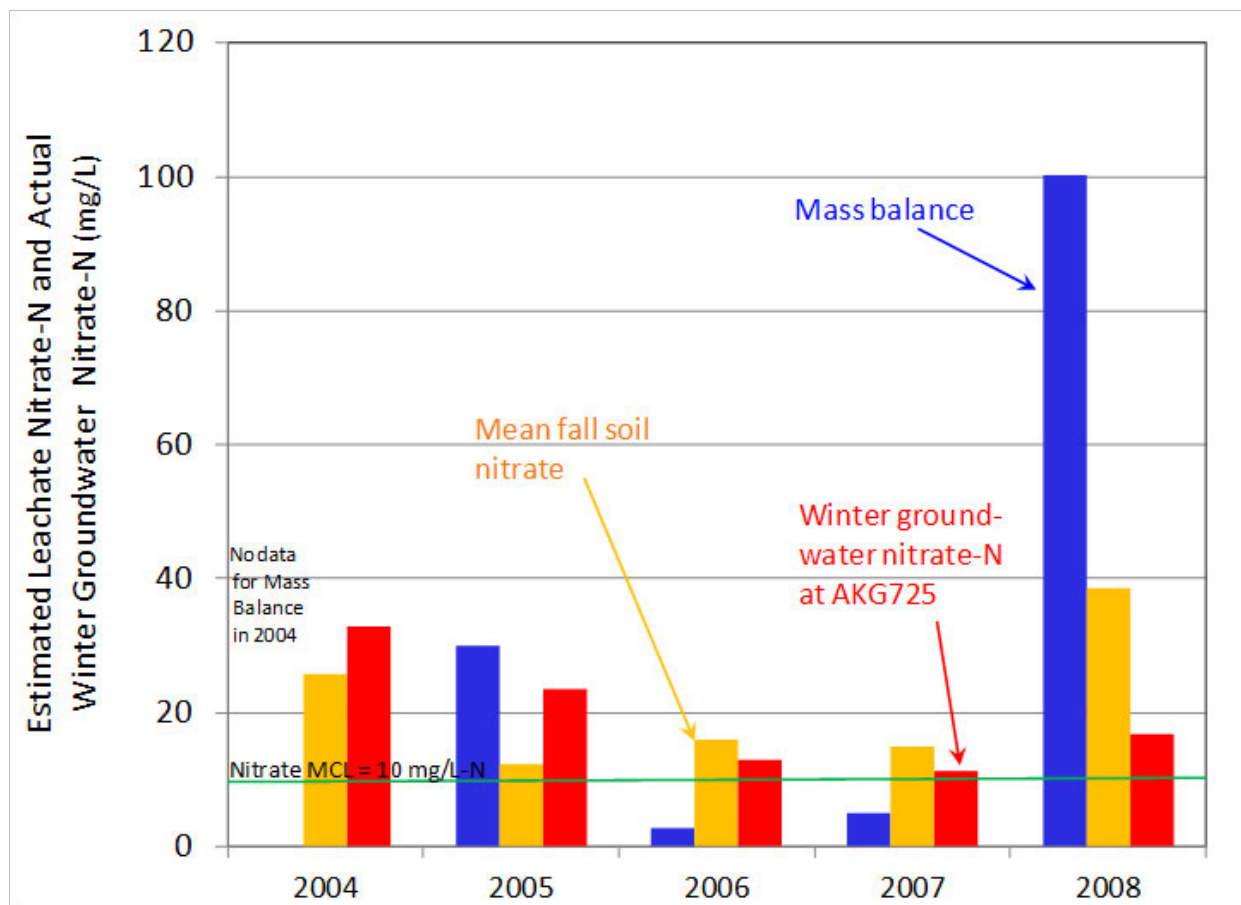


Figure 55. Nitrate-N leachate concentration estimates and mean November to December groundwater nitrate concentration at AKG725 (mg/L): Method A (Mass balance-blue), B (Mean fall soil nitrate [September to October]-gold), and actual mean winter groundwater nitrate-N (red).

How protective is the current soil nitrate target?

Harter et al (2012) suggested that a fall soil nitrate value of 31 lb/acre will result in a “low” intensity of nitrate leaching in the Salinas Valley/Tulare Lake Basin areas of California, warning that above this level there is a high potential for groundwater degradation. This threshold is based on the fact that the amount of nitrate required to reach the MCL, 10 mg/L nitrate-N, with one acre-foot of recharge, typical for the Central Valley of California, is 27 lb nitrogen/acre. They added 4.5 lb N/acre to allow for potential denitrification before the leachate reaches the water table.

The strategy of setting a goal for soil nitrate based on recharge does not take into account the fact that not all of the soil nitrate leaches at the same time, more nitrate is generated after the fall soil sampling, and typically the more recharge that occurs the more nitrate leaches to groundwater.

Implications for other parts of the aquifer

This study site represents a nearly best case for attenuating nitrate leaching due to denitrification when compared to other parts of the Sumas-Blaine Aquifer. DO in 4 out of 6 shallow monitoring wells was at least occasionally below 2 mg/L, the threshold for denitrification.

In aquifers where depth to groundwater is greater or infiltration rates slower than at the study site, the impact of nitrate leaching from the soil to groundwater may be delayed by months or even years. Higher recharge rates in areas with higher precipitation can also intensify nitrate concentrations in groundwater.

Conclusions

The purpose of this study was to document the impacts of manure application on groundwater beneath a dairy field overlying the SBA. This goal was accomplished by conducting a mass balance evaluation of nitrogen inputs, outputs, and residuals at a 20-acre study field near the western edge of the aquifer system. The residual nitrogen mass (in the form of root-zone soil nitrate) was compared to the underlying groundwater nitrate condition to assess the combined impact of manure management and recharge on the aquifer.

Intensive monitoring showed that management practices at the manured dairy field over the SBA resulted in groundwater nitrate-N concentrations consistently higher than the state groundwater quality standard of 10 mg/L. Despite loss of a portion of the residual nitrate due to denitrification, 65 percent of 308 shallow groundwater nitrate-N results were above 10 mg/L, with a maximum concentration of 45 mg/L.

Following are the key study findings.

Factors affecting groundwater nitrate concentration

Groundwater conditions underlying the study field on any given day were the result of a complex interaction between the following main factors:

- **Nitrogen application rate** – The balance between the amount of nitrogen applied to the field versus the amount of nitrogen removed by harvest was an overriding factor affecting groundwater nitrate concentrations. During the study, groundwater concentrations tended to be higher in years with a large residual excess N value (2005, 2008); concentrations were lower when the N application rate was in close balance with the rate of crop removal (2006, 2007). This indicates that, to minimize the impact to groundwater quality, manure applications need to be precisely tuned to the crop demand.
- **Timing of nitrogen application** – The rate of loss of soil nitrate to underlying groundwater is highly sensitive to the time of application. If manure is applied to a field during a period of the year when crop growth rates are declining and recharge is increasing, excess nitrate is prone to leach downward. During the study, application of manure past the end of the typical growing season resulted in a corresponding rise in underlying groundwater nitrate concentration. Likewise manure applications early in the year may add to the recently mineralized and lead to significant transport to groundwater. This indicates that the application of manure during the months when precipitation exceeds evapotranspiration (October through March) presents a high risk for nitrate leaching to groundwater.
- **Rate and timing of recharge** – The amount of recharge that infiltrates the soil column during the months following the final harvest can have a significant effect on the amount of nitrate leaching to the water table. Recharge serves as the primary transport mechanism for nitrate stored in soils at the end of the growing season; the more recharge that moves through the root zone, the more the nitrate stored in soils will be transferred to the dissolved phase and carried rapidly to the water table. This process can be compounded by a corresponding

rise in the water table (also driven by recharge), shortening nitrate transport distances and times. This implies that nitrogen should not be applied in significant quantities during periods of significant recharge.

- **Soil temperature and soil moisture** – During the growing season, the degree of imbalance between nitrogen application and crop uptake is sensitive to both soil temperature and soil moisture. If soils are warm and have enough moisture to sustain plant growth, crop growth is active and nitrogen uptake is maximized. As soil temperature drops or soil moisture declines, plant growth and related nitrogen uptake also decline. The highest year for thermal input to the grass crop, 2007, coincided with the highest crop nitrogen removal and the lowest groundwater nitrate concentration the following winter. In 2008, lower crop uptake and the highest applied excess nitrogen resulted in winter groundwater nitrate increases. This indicates that soils should be kept adequately moist during the growing season.
- **Denitrification** – If the proper conditions are present, conversion of nitrate to nitrogen gas by microbes in the subsurface can help to reduce the concentration of nitrate in groundwater. During the study, 4 out of 6 of the shallow monitoring wells exhibited periodic low dissolved oxygen conditions conducive to denitrification. This factor probably muted the effects of excess nitrogen on the groundwater sampled from these wells. This suggests that impacts on groundwater nitrate conditions will probably be more pronounced in areas where groundwater dissolved oxygen rates are high and denitrification rates are low.
- **Decrease in groundwater nitrate concentration over the 1st 3 years** – The nitrate concentration in groundwater underlying the study field generally declined over the first three years of the study. This decline is interpreted to be primarily the result of a steady reduction in the amount of nitrogen applied to the field, an improved balance between application rate and crop demand, and declining fall recharge. In the fourth year of the study, groundwater concentrations increased, primarily due to a large overbalance in the amount of nitrogen applied to the field during the growing season. Based on the annual mass balance analysis, the estimated annual nitrate loss to groundwater was 38 to 284 lb-N/acre.

Fall soil nitrate as an estimator of groundwater impacts

In some circumstances fall soil nitrate tests may help dairy producers evaluate the amount of nitrate left at the end of the growing season. However, soil nitrate is not a reliable tool for accurately predicting groundwater impacts. Wide variability was observed in the fall soil nitrate concentration, depending on timing of the sampling. Manure applications and precipitation events occurring during the fall sampling period had a significant role in this variability. However when sampled more than one time immediately after the last harvest, and if no additional manure applications are made, the fall soil nitrate test can be a useful tool for producers to assess the general range of nitrate left in the soil.

Because it takes so little nitrate to have a significant effect on groundwater, the inherent variability in soil nitrate, the difficulty estimating recharge without field studies, and the on-going leaching of nitrate after the main fall flush preclude soil nitrate from predicting groundwater impacts.

Estimated nitrate concentrations in leachate

Estimates of the nitrate concentrations of leachate infiltrating below the root zone were developed for each study year by integrating end-of-season mass estimates of nitrate in the soil column with the subsequent fall recharge volume. This revealed leachate nitrate-N concentrations ranging between 8 and 107 mg/L.

Because of the complex interactions described above (attenuation reactions, timing and amount of recharge, variation in crop uptake due to weather and irrigation, and the concentration of groundwater flowing in from upgradient), estimates of the soil column leachate concentration were a generally poor predictor of nitrate conditions observed at the water table. This indicates that direct monitoring of groundwater using monitoring wells screened across the water table is needed to accurately characterize impacts of manure application on aquifer water quality.

Use of the current soil N 55 lb/acre target to protect groundwater

The current fall soil N target recommendation of 55 lb/acre was not developed to take groundwater impacts into account and may consistently produce fall/early winter leachate concentrations that are greater than the groundwater quality standard of 10 mg/L nitrate-N.

During the study the range of maximum fall soil nitrate values from September 1 through November 15 was 89 to 210 lb/acre, or 1.7 to 3.8 times the fall soil nitrate target for nutrient balance in western Washington (55 lb/acre). This is longer than the typical range of time for collecting post harvest soil nitrate samples, because we were interested in observing the maximum for the season, not just the concentration immediately after harvest.

The calculated leachate nitrate-N concentration that would result from combining the fall soil nitrate threshold concentration for grass (55 lb/acre) with the observed annual volume of recharge ranged from 10 to 21 mg/L.

These points suggest that the post-harvest soil nitrate guidance for the amount of soil nitrate considered acceptable with no changes in management needed should be reviewed and revised to take groundwater impacts into account.

Implications for other parts of the Sumas Blaine Aquifer

Grain size analyses and hydraulic testing of the shallow aquifer suggest that the study site is generally finer-grained than most of the SBA, a finding consistent with the position of the site at the margins of the aquifer system (where sediment transport energies are typically lower). The finer grained character of the deposits underlying the study field result in slower transport velocities and low dissolved oxygen, conditions conducive to denitrification.

Loss of nitrate via denitrification in the subsurface was probably higher than would be expected in coarse-grained areas, where dissolved oxygen is typically near saturation. Nitrate impacts to

groundwater from manure management practices similar to those monitored in this study would probably be more severe in areas of the aquifer with high dissolved oxygen.

Increasing precipitation from west to east over the SBA translates into increasing recharge to groundwater from west to east. Increasing recharge can hasten nitrate movement below the root zone which increases the load of nitrate to groundwater.

These points suggest that the results observed during the study do not represent a worst case scenario, and possibly represent a best case scenario, for the impact of manure application practices on underlying groundwater.

Recommendations

Reversing groundwater contamination in agricultural areas with high concentrations of dairy farms will require two major actions: 1) reducing nitrate loading to groundwater, and 2) improving the monitoring needed to evaluate the effectiveness of measures to reduce nitrate loading. Based on the results of this study, we believe the following actions are needed to promote improvements to groundwater quality in the SBA and in other areas of Washington with extensive manure application.

Reduce nitrate loading to groundwater from manure application

Develop a process whereby nitrogen inputs and removal are carefully measured, recorded, and used to evaluate nitrogen mass balances and residuals on individual fields. This information is needed to adjust nitrogen application on an on-going process. Involvement of state and local organizations in partnership with universities is needed to help farmers improve nitrogen use efficiency, whereby more of the nitrogen applied is removed in the crop and less is left in the soil column for leaching to groundwater.

Some of the lessons learned in this study that could decrease nitrate leaching to groundwater in the SBA include:

12. Ensure that nitrogen inputs (manure, fertilizer, irrigation water) and outputs (crop removal) are measured accurately and are in close balance to minimize end-of-season residual nitrogen to prevent excessive nitrate loading to groundwater. This is especially important in areas where groundwater nitrate already does not meet the drinking water standard OR areas with limited denitrification potential.
13. Pay close attention the timing of nitrogen application. Schedule the last manure application to occur by mid-September. Manure should not be applied during months with a significant water surplus (October through mid-March).
14. Where groundwater is well oxygenated and denitrification rates are low, take special care to apply manure at the proper times and amounts.
15. Avoid manure application early in the year when surplus water is high and crop uptake of nitrogen is low (January/February).
16. Minimize use of inorganic fertilizer on manured fields. If soil moisture is low in the summer, consider irrigating to increase mineralization and nitrification to increase available nitrate to the crop.
17. Where irrigation water is available, apply as needed during the growing season based on field soil moisture data to promote maximum nitrogen uptake and removal.
18. Extend the time between tillage events to decrease the amount of nitrogen reaching groundwater.
19. Avoid applying manure to forage crops during the first season following tillage.

20. Improve soil nitrate sampling by taking multiple samples beginning in late September in each manured field (assuming that the last manure application is made by mid-September) and collecting spring soil nitrate samples prior to the first application of the year. Data from both fall and spring soil sampling should be a key factor in decisions regarding the amount and timing of future manure application. (It is important to keep in mind the high variability of soil nitrate results and the potential for leaching before samples are collected.)
21. Track off-site manure transport and application and ensure that application is included in target field's nutrient management plan. Encourage cultivation of grass and perennial crops that can uptake up to 4 times more nitrogen annually than corn.
22. Compare results from this study with results of the current Whatcom Conservation District's Application Risk Management System study.

Monitor to evaluate the effectiveness of management improvements

A program is needed to determine how well manure management improvements are working to improve groundwater quality. Direct groundwater monitoring using dedicated monitoring wells should be an integral component of any effectiveness monitoring program.

There is no substitute for groundwater monitoring for evaluating either the amount or the concentration of nitrate that actually reaches the water table. However, fall soil nitrate monitoring is a necessary tool for on-farm nutrient management. If conducted with limitations in mind, soil nitrate monitoring could serve as a screening tool to focus closer inspection of groundwater conditions.

Investigate improvements in soil nitrate sampling by producers so that they have as accurate information as possible for scheduling manure management, i.e., taking multiple samples beginning in late September in each manured field (assuming that the last manure application is made by mid-September) and collecting spring soil nitrate samples prior to the first application of the year. Data from both fall and spring soil sampling should be one (but not the sole) factor in decisions regarding the amount and timing of future manure application.

References

APHA, 2005. Standard Methods for the Analysis of Water and Wastewater, 21st Edition. Joint publication of the American Public Health Association, American Water Works Association, and Water Environment Federation. www.standardmethods.org/.

ASTM Standard D422-63(2003). "Standard Test Method for Particle-Size Analysis of Soils." DOI: 10.1520/D0422-63R07. American Society for Testing and Materials, Philadelphia, PA.

Associated Earth Sciences, Inc., 2009. Installation and testing: Streamflow augmentation well, DeHaan property, Whatcom County. Prepared for Reichhardt and Ebe Engineering, Inc., 31 p. + appendices.

Bary, A., 2010. Personal communication. Washington State University Puyallup Research Station, Soil Scientist.

Basso, B., J. T. Ritchie, 2005. Impact of compost, manure and inorganic fertilizer on nitrate leaching and yield for a 6-year maize-alfalfa rotation in Michigan. Agriculture Ecosystems, and Environment. Volume 108, p. 329-341.

Bates, H. K. and R. F. Spalding, 1998. Aquifer denitrification as interpreted from in situ microcosm experiments. Journal of Environmental Quality, Volume 27, p. 174-182.

Beegle, D. B., K. A. Kelling, and M. A. Schmitt, 2008. Nitrogen in animal manures. Chapter 21 in Nitrogen in Agricultural Systems, ed. by J. S. Schepers and W. R. Raun. Agronomy Monograph 49. American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America. p. 823-881.

Bergstrom, L. 1987. Nitrate leaching and drainage from annual and perennial crops in tile-drained plots and lysimeters. Journal of Environmental Quality, Volume 16, p.11-18.

Bittman, S. 2012. Agriculture and Agri-Food Canada. Agassiz Research Station, British Columbia, personal communication. Date? Email?

Bradbury, K. R. and E. R. Rothschild, 1985. A computerized technique for estimating the hydraulic conductivity of aquifers from specific capacity data. Ground Water, Volume 23(2), p. 240-246.

Brisbin, P. E., 1995. Agricultural nutrient management in the Lower Fraser Valley, Lower Fraser Action Plan. Ministry of the Environment, Environment Canada, and Ministry of Agriculture Fisheries and Food, Vancouver, B.C.

Boumans, L.J.M., D. Fraters, and F. Van Dreht, 2005. Nitrate leaching in agriculture to upper groundwater in the sandy regions of the Netherlands during the 1992-1995 period. Environmental Monitoring and Assessment Volume 102, p. 225–241.

Bouwer, H., 1995. Estimating the ability of the vadose zone to transmit liquids. In Handbook of Vadose Zone Characterization and Monitoring, ed. by L.G. Wilson, L.G. Everett, and S.J. Cullen. CRC Press, Boca Raton, FL, p. 177-188.

Buss, S. R., M. O. Rivett, P. Morgan, C. D. Bemment, 2005. Attenuation of nitrate in the sub-surface environment. Environment Agency-UK. Almondsbury, Bristol. Science Report SC030155/SR2. 100 pages.

Buss, S. R., A. W. Herbert, P. Morgan, S. F. Thornton, and J. W. N. Smith, 2004. A review of ammonium attenuation in soil and groundwater. *Quarterly Journal of Engineering Geology and Hydrogeology*, Volume 37, p. 347-359.

California Regional Water Quality Control Board Central Valley Region, 2007. Order No. R5-2007-0035. Waste discharge requirements general order for existing milk cow dairies http://www.swrcb.ca.gov/rwqcb5/board_decisions/adopted_orders/general_orders/r5-2007-0035.pdf

Carey, B., 2004. Quality Assurance Project Plan: Groundwater, Soil, and Crop Nitrogen at a Field Where Dairy Waste is Used as Fertilizer in Whatcom County. Washington State Department of Ecology, Olympia, WA. 32 pages. Publication No. 04-03-112. www.ecy.wa.gov/biblio/0403112.html.

Carey, B., 2002. Effects of land application of manure on groundwater at two dairies over the Sumas-Blaine Surficial Aquifer: Implications for agronomic rate estimates. Washington State Department of Ecology, Olympia, WA. 75 pages. Publication No. 02-03-007. www.ecy.wa.gov/biblio/0203007.html.

Centers for Disease Control and Prevention, 1996. Spontaneous abortions possible related to ingestion of nitrate-contaminated well water, La Grange County, Indiana, 1991-1994. *Morbidity and Mortality Weekly Report*, Volume 45, p. 569-572.

Chang, A. 2006. Illustration of nitrogen leaching losses in manure systems subject to organic nitrogen mineralization. Appendix C. In: University of California Committee of Experts on Dairy Manure Management, 2006. Groundwater quality protection: Managing manure in the Central Valley of California, 178 p.

Chesnaux, R. and D. M. Allen, 2007. Simulating Nitrate Leaching Profiles in a Highly Permeable Vadose Zone. *Environmental Modeling and Assessment*, Volume 13, Number 4, p. 527-539.

Chesnaux, R. and D. M. Allen, and G. Graham, 2007. Assessment of the Impact of Nutrient Management Practices on Nitrate Contamination in the Abbotsford-Sumas Aquifer. *Environmental Science and Technology*, Vol. 41, p. 7229-7234.

Clark, C., 2012. Whatcom Conservation District. Lynden, Washington. Personal communication.

Cogger, C., 2013. Washington State University, Department of Crop and Soil Sciences. Email communication, March 3, 2013.

Cookson, W.R., I. S. Cornforth, and J. S. Rowarth, 2002. Winter soil temperature (2-15°C) effects on nitrogen transformations in clover green amended manure or unamended soils; a laboratory and field study. *Soil Biology and Biochemistry*, Volume 34, p. 1401-1415.

Coyne, M.S., 2008. Biological denitrification. Chapter 7 in Nitrogen in Agricultural Systems. ed. by J. S. Schepers and W. R. Raun. Agronomy Monograph 49. American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America. p. 201-253.

Cox, S. E. and S. C. Kahle, 1999. Hydrogeology, ground water quality, and sources of nitrate in lowland glacial aquifers of Whatcom County, Washington, and British Columbia, Canada. U.S. Geological Survey Water-Resources Investigations Report 98-4195. 251 pages, 5 plates.

Creahan, K. and H. M. Kelsy, 1988. Hydrogeology and groundwater flow near Lynden, Washington. Final report for Washington State Department of Ecology Hazardous Waste Cleanup Program Contract C0087216, September 30, 1988. 74 p.

Derby, N. E., F. X. M. Casey, and R. E. Knighton, 2009. Long-term observations of vadose zone and groundwater nitrate concentrations under irrigated agriculture. *Vadose Zone Journal*, Vol. 8:290-300.

Desimone, L.A. and B.L. Howes, 2006. Denitrification and nitrogen transport in a coastal aquifer receiving wastewater discharge. *Environmental Science and Technology*, Volume 30, No. 4, p. 1152-1162.

de Ruijter, F. J., L. J. M. Boumans, A. L. Smit, and M. van den Berg, 2007. Nitrate in upper groundwater on farms under tillage as affected by fertilizer use, soil type and groundwater table. *Nutrient Cycling in Agroecosystems*, Volume 77, p. 155-167.

Di, H.J. and K.C. Cameron, 2002. Nitrate leaching in temperate agroecosystems: sources, factors and mitigating strategies. *Nutrient Cycling in Agroecosystems*, Volume 46, p. 237-256.

Downing, T. W., 2008. Case study: Impact of manure application timing in dairy pastures on the migration of nitrates to groundwater. *The Professional Animal Scientist*, Vol. 24, p. 100-102.

Dzurella, K.N., J. Medellín-Azuara, V. B. Jensen, A. M. King, N. De La Mora, A. Fryjoff-Hung, T. S. Rosenstock, T. Harter, R. Howitt, A. D. Hollander, J. Darby, K. Jessoe, J. Lund, G. S. Pettygrove, 2012. Nitrogen source reduction to protect groundwater quality with a focus on Tulare Lake and Salinas Valley groundwater. Report to the State Water Resources Control Board Report to the Legislature. California Nitrate Project, Implementation of Senate Bill X2 1, University of California, Davis. Center for Watershed Studies, Technical Report 3. 174 p.
<http://groundwaternitrate.ucdavis.edu/files/139103.pdf>

Easterbrook, D. J., 1971. Geology and geomorphology of western Whatcom County. Western Washington University, Department of Geology, 68 pages.

Embertson, N., 2010. Protecting Puget Sound Watersheds from Agricultural Runoff Using a Progressive Manure Application Risk Management (ARM) System. EPA Grant Application, Protecting Watersheds, Water Quality and Aquatic Resources from the Impacts of Growth, FFYI 2010.

Erickson, D., 2000. Northcentral Sumas-Blaine Surficial Aquifer Nitrate Characterization Project – June 1999. Washington State Department of Ecology, Olympia, WA. Publication No. 00-03-010, 13 pages. www.ecy.wa.gov/biblio/0003010.html.

Erickson, D., 1998. Sumas-Blaine Surficial Aquifer Nitrate Characterization. Washington State Department of Ecology, Olympia, WA. 27 pages. Publication No. 98-310. www.ecy.wa.gov/biblio/98310.html

Erickson, D., 1991. Edaleen dairy lagoon groundwater quality assessment, February 1990 to February 1991. Washington State Department of Ecology, Olympia, WA. 32 pages + appendices. Publication No. 91-e11. www.ecy.wa.gov/biblio/91e11.html.

Erickson, D. and D. Norton, 1990. Washington State Agricultural Chemicals Pilot Study, Final Report. Washington State Department of Ecology, Olympia, WA. 76 pages + appendices. Publication No. 90-46. www.ecy.wa.gov/biblio/9046.html.

Freeze, R.A. and J. A. Cherry, 1979. Groundwater. Prentice-Hall, Inc. 604 p.

Garland, D. and D. Erickson, 1994. Ground water quality survey near Edaleen Dairy, Whatcom County, Washington, January 1990 to April 1993. Washington State Department of Ecology, Olympia, WA. 20 pages + appendices. Publication No. 94-37. www.ecy.wa.gov/biblio/9437.html.

Gillham, R. W. and J. A. Cherry, 1978. Field evidence of denitrification in shallow groundwater flow systems. Water Pollution Research Journal Canada. Vol. 13, p. 53-71.

Goss, M.J. and D. Goorahoo, 1995. Nitrate contamination of groundwater: Measurement and prediction. Fertilizer Research, Volume 42, p. 331-338.

Goulding, K.W.T., P.R. Poulton, C.P. Webster, M.T. Howe, 2000. Nitrate leaching from the Broadbalk Wheat Experiment, Rothamsted, UK, as influenced by fertilizer and manure inputs and weather.

Graham, G., 2013. Presentation to the Abbotsford-Sumas International Task Force Meeting, January 17, 2013. Abbotsford, B.C.

Graham, G., 2008. Presentation to the Abbotsford Aquifer Meeting, March 12, 2008. Abbotsford, B.C.

Green, C.T., L. J. Puckett, J. K. Böhlke, B. A. Bekins, S. P. Phillips, L. J. Kauffman, J. M.

Denver, and H. M. Johnson, 2008. Limited Occurrence of Denitrification in Four Shallow Aquifers in Agricultural Areas of the United States. *Journal of Environmental Quality*. Volume 37, p. 994–1009.

Griffith S. M. and T. W. Thomson. 1996. N rate and timing relationships with tissue N concentration and seed yield in perennial ryegrass. Seed Production Research at Oregon State University.

Harter, T. H, J. R. Lund (Principal investigators), 2012. Addressing nitrate in California's drinking water with a focus on the Tulare Lake Basin and the Salinas Valley groundwater—Report to the State Water Resources Control Board Report to the Legislature. California Nitrate Project, Implementation of Senate Bill X2 1, University of California, Davis. Center for Watershed Studies, Technical Report 1.
<http://groundwaternitrate.ucdavis.edu/files/138956.pdf>

Harter, T. and J. Menke, 2005. Cow numbers and water quality—is there a magic limit? A groundwater perspective. Revision of manuscript in Proceedings, National Alfalfa Symposium, 13-15 December 2004, San Diego, CA; UC cooperative Extension, University of California, Davis, 95616. See <http://alfalfa.ucdavis.edu> for proceedings.

Harter, T., H. Davis, Marsha C. Mathews, Roland D. Meyer, 2002. Shallow groundwater quality on dairy farms with irrigated forage crops, *Journal of Contaminant Hydrology* Vol. 55 No. 3-4, pp. 287-315.

Healy, R. and Cook, P. 2002. Using groundwater levels to estimate recharge. *Hydrogeology Journal* 10, 91-109.

Hermanson, R., W. Pan, C Perillo, R. Stevens, C Stockle, 2000. Nitrogen use by crops and the fate of nitrogen in the soil and vadose zone: A literature search. Washington State University and Washington State Department of Ecology. Publication No. 00-10-015. 248 p.

Hirsch, H., 2007. Applicability of the NLOS Model for Predictions of Soil Water Movement and Nitrogen Transport in an Agricultural Soil, Agassiz, BC. M.S. thesis. Western Washington University, ? p.

Howarth, R.W. and R. Marino, 2006. Nitrogen as the limiting nutrient for eutrophication in coastal marine ecosystems: Evolving views over three decades. *Limnology and Oceanography*, Volume 51, p. 364-376.

Jones, M. A., 1999. Geologic framework for the Puget Sound Aquifer System, Washington and British Columbia. Regional Aquifer-System Analysis—Puget-Willamette Lowland. U.S. Geological Survey Professional Paper 1424-C, 32 p, 18 plates.

Keller, C.K., C.N. Butcher, J.L. Smith, and R.M. Allen-King, 2008. Nitrate in tile drainage of the semiarid Palouse Basin. *Journal of Environmental Quality*, Volume 37, p. 353-361.

Kirchmann, H., A.E. Johnny Johnsotn, L. F. Bergstrom, 2002. Possibilities for reducing nitrate leaching from agricultural land. Royal Swedish Academy of Sciences. *Ambio*. Vol. 31(5), p. 404-408.

Kohut, A. P., 1987. Groundwater supply capability Abbotsford Upland: Victoria, British Columbia, British Columbia Ministry of the Environment, Open File Report, 18 p.

Kowalenko, C. G., 1989. The fate of applied nitrogen in a Fraser Valley soil using ^{15}N in field microplots. *Canadian Journal of Soil Science*. Volume 69, p. 825-833.

Kowalenko, C. G., 1987. The dynamics of inorganic nitrogen in a Fraser Valley soil with and without spring or fall ammonium nitrate applications. *Canadian Journal of Soil Science*. Volume 67, p. 367-382.

Landstrom, S., L. Lomakka, and S. Andersson, 1996. Harvest in spring improves yield and quality of reed canary grass as a bioenergy crop. *Biomass and Bioenergy*, Vol. 11, No. 4, p. 333-341.

Loo, S. and C. Ryan, 2012. University of Calgary, Department of Geosciences. Unpublished data.

McArthur, S. and D. Allen, 2005. Abbotsford-Sumas Aquifer--Compilation of a groundwater chemistry database with analysis of temporal variations and spatial distributions of nitrate contamination. Department of Earth Sciences Simon Fraser University, Burnaby, B.C. V3Y 2L4. Prepared for the B.C. Ministry Water, Land and Air Protection--Climate Change Branch, 50 p.

McCallum, J. E, M. C. Ryan, B. Mayer, and S. J. Rodvang, 2008. Mixing-induced groundwater denitrification beneath a manured field in southern Alberta, Canada. *Applied Geochemistry*, Volume 23, p. 2146-2155.

MEL, 2006. Manchester Environmental Laboratory Quality Assurance Manual. Manchester Environmental Laboratory, Washington State Department of Ecology, Manchester, WA.

MEL, 2008. Manchester Environmental Laboratory Lab Users Manual, Ninth Edition. Manchester Environmental Laboratory, Washington State Department of Ecology, Manchester, WA.

Marti, P., 2011a. Standard Operating Procedure for Purging and Sampling water supply wells. Washington State Department of Ecology draft SOP EAP077. 32 p.

Marti, P., 2011b. Standard Operating Procedure for Purging and Sampling Monitoring Wells. Washington State Department of Ecology draft SOP EAP078. 34 p.

Marti, P., 2009. Standard Operating Procedure for Manual Well-Depth and Depth-to-Water Measurements. Washington State Department of Ecology SOP EAP052. 31 p.

- Magdoff, F.R., 1978. Influence of manure application rates and continuous corn on soil-N. *Agronomy J.* Vol. 70, p. 629-632.
- McCallum, J.E, M.C. Ryan, B. Mayer, and S.J. Rodvang, 2008. Mixing-induced groundwater denitrification beneath a manured field in southern Alberta, Canada. *Applied Geochemistry*, Volume 23, p. 2146-2155.
- Meisinger, J. J., F.J. Calderon, and D.S. Jenkinson, 2008. Soil nitrogen Budgets, in Nitrogen in Agricultural Systems, ed. by J.S. Schepers and W.R. Raun. *Agronomy Monograph* 49. ASA, CCSA, SSSA. 965 p.
- Miller, J. F., 1973. Precipitation—Frequency Atlas of the Western U. S., Volume IX, Washington. U. S. Department of Commerce, National Oceanic and Atmospheric Administration.
- Murray, R.E., Y.S. Fieg and J.M. Tiedje, 1995. Spatial heterogeneity in the distribution of denitrifying bacteria associated with denitrification activity zones. *Applied and Environmental Microbiology*, Vol. 61, No. 7, p. 2791-2793.
- Marti, Pamela, 2009, Standard operating procedure for manual well-depth and depth-to-water measurements. Washington State Department of Ecology, Environmental Assessment Program, EAP052, Version 1.0. http://teams/sites/EAP/gwtct/SOPs/Water_level_measurement_v10.pdf
- Matson, P.A., W.J. Parton, A.G. Power, and M.J. Swift, 1997. Agricultural intensification and ecosystem properties. *Science*, Volume 277, p. 504-509.
- Mitchell, R., S. Babcock, H. Hirsch, L. McKee, R. Matthews, and J. Vandersypen, 2005. Water Quality: Abbotsford-Sumas Final Report. Western Washington University, Bellingham, WA, 144 pages. http://kula.geol.wvu.edu/rjmitch/Report_2005.pdf.
- NOAA, 2011. National Climatic Data Center. Surface data for Clearbrook, WA. : www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwDI~GetCity~USA
- NRCS, 2012. National Handbook of Conservation Practices. Conservation Practice Standard Code 590. Nutrient management.
- NRCS, 2006. Natural Resources Conservation Service, Washington Supplements to the Agricultural Waste Management Field Handbook (AWMFH). NEH Part 651. Tables WA651.105-22(2) and WA651.105-22(3) . <http://www.wa.nrcs.usda.gov/technical/ENG/waawmfh/index.html>
- NRCS, 2005. Winter period application of manure in Washington State. Technical Note, *Agronomy* 14, 7 p.
- NRCS, 1996. Natural Resources Conservation Service, Agricultural Waste Management Field Handbook. Chapter 11. Waste Utilization.

Norton, J. M., 2008. Nitrification in agricultural soils. In Nitrogen in Agricultural Systems, ed. J.S. Schepers and W.R. Raun. Agronomy Monograph 49. ASA, CCSA, SSSA. 965 p.

Obert, W. C., 1973. Nitrate in groundwater, Western Whatcom County, Washington. Western Washington University, Bellingham, Washington, MS thesis. Department of Geography. 167 pages.

Oenema, J, S. Burgers, and K. Verloop, 2010. Multiscal effects of management, environmental conditions, and land use on nitrate leaching in dairy farms. *Journal of Environmental Quality*, Volume 39, p. 2016-2028.

Paul, J. W., V. Etches, and B. J. Zebarth, 1997. Increased denitrification below the root zone in the fall following a spring manure application. *Canadian Journal of Soil Science*. Volume 77, p. 249-251.

Paul, J. W. and B. J. Zebarth, 1997. Denitrification and nitrate leaching during the fall and winter following dairy cattle slurry application. *Canadian Journal of Soil Science*. Volume 77, p. 241-248.

Pell, D., 2011. Washington Department of Health, Northwest Office of Drinking Water, Kent, Washington. Email communication August 19, 2011.

Pfluke, P. D., W. E. Jokela, and S. C. Bosworth, 2011. Ammonia volatilization from surface-banded and broadcast application of liquid dairy manure on grass forage. *Journal of Environmental Quality*, Volume 40, p. 374-382.

Prest, V., 2011. Washington Department of Agriculture, Olympia, Washington. Email communication March 3, 2011.

Redding, M. , 2008. Nitrate trends in the Central Sumas-Blaine Aquifer. Washington State Department of Ecology, Olympia, WA. 117 pages. Publication No. 08-03-018. www.ecy.wa.gov/biblio/0803018.html

Rodvang, S. J., D. M. Mikalson, and M.C. Ryan, 2004. Changes in groundwater quality in an irrigated area of southern Alberta. *Journal of Environmental Quality*, Volume 33, p. 476-487.

Rozemeijer, J.C, H.P. Broers, F.C. van Geer, M.F.P. Bierkens, 2009. Weather-induced temporal variations in nitrate concentrations in shallow groundwater. *Journal of Hydrology*, Volume 378, p. 119–127.

Ryan, C. 2008. Presentation to the Abbotsford Aquifer Meeting, March 12, 2008. University of Calgary, Department of Geoscience, Calgary, Alberta.

Sawyer, and McCarty, 1978. *Chemistry for Environmental Engineering*. McGraw Hill Book Company, San Francisco, CA. 532 p.

SCS, 1992. Soil Survey of Whatcom County Area, Washington. U.S. Soil Conservation Service, Spokane, WA.

Sikkema, A. May 12, 2011. Dairy sector fails to reach environmental targets. Resource for Wageningen UR students and employees.

Sinclair, K., 2002. A comparison of horizontal hydraulic conductivity values derived from aquifer test and well specific-capacity data for the Sequim-Dungeness Area. Washington State Department of Ecology, Olympia, WA. 12 pages. Publication No. 02-03-017. www.ecy.wa.gov/biblio/0203017.html.

Singleton, M. J., B. K. Esser, J. E. Morgan, G. B. Hudson, W. W. McNab, and T. Harter, 2007. Saturated zone denitrification: Potential for natural attenuation of nitrate contamination in shallow groundwater under dairy operations. *Environmental Science and Technology*. Vol. 41, p. 759-765.

Smith, K.A., C.P. Beckwith, A.G. Chalmers, and D.R. Jackson, 2002. Soil Use and Management, Vol. 18, p. 428-434.

Sonneveld, M. P. W., D. J. Brus, and J. Roelsma, 2010. Validation of regression models for nitrate concentrations in the upper groundwater in sandy soils. *Environmental Pollution*, Volume 158, p. 92-97. doi:10.1016/j.envpol.2009.07.033.

Stallman, R. W., 1983, U.S. Geological Survey, Techniques of Water-Resources Investigations, Book 3, Chapter B: Aquifer-Test Design, Observation, and Data Analysis. http://pubs.usgs.gov/twri/twri3-b1/pdf/twri_3-B1_a.pdf.

Starr, R.C. and R.W. Gillham, 1993. Denitrification and organic carbon availability in two aquifers. *Ground Water*, Volume 31(6), p. 934-947.

Stasney, D. V., 2000. Hydrostratigraphy, groundwater flow, and nitrate transport within the Abbotsford Sumas Aquifer, Whatcom County. M.S. Thesis, Western Washington University, Bellingham, WA. 154 pages + CD.

Sullivan, D. M. and C. G. Cogger, 2003. Post-harvest soil nitrate testing for manured cropping systems west of the Cascades. Oregon State University Extension. Publication EM 8832-E. 17 pages. <http://extension.oregonstate.edu/catalog/pdf/em/em8832-e.pdf>.

Sullivan, D. M., H. Bierlink and W. Matthews, 1994. Tools for getting more value out of dairy manure. , p. 55-65. In: *Proceedings of the 26th Annual Dairy Producers Short Course*, Feb. 8-9, 1994, Clearbrook, BC., Canada. BC Ministry of Agriculture, Fisheries and Food, Chilliwack, BC.

Sweeney, M., 2012. British Columbia Ministry of Agriculture. Presentation at the Abbotsford-Sumas Aquifer Nitrate Forum, Abbotsford, B.C, May 2, 2012.

Tooley, J. and D. Erickson, 1996. Nooksack Watershed Surficial Aquifer Characterization. Washington State Dept. of Ecology, Olympia, WA. 12 pages + appendices and plates. Publication No. 96-311. www.ecy.wa.gov/biblio/96311.html.

Trindade, H., J. Coutinho, S. Jarvis, and N. Moreira, 2001. Nitrogen mineralization in sandy loam soils under an intensive double-cropping forage system with dairy-cattle slurry applications. European Journal of Agronomy, Volume 15, p. 281-293.

U.S. Census, 2010. <http://www.census.gov/2010census/>

U.S. EPA Advisory Board, 2011. Reactive nitrogen in the United States: An analysis of inputs, flows, consequences, and management options. EPA-SAB-11-013/August 2011. 139 p. [http://yosemite.epa.gov/sab/sabproduct.nsf/WebBOARD/67057225CC780623852578F10059533D/\\$File/EPA-SAB-11-013-unsigned.pdf](http://yosemite.epa.gov/sab/sabproduct.nsf/WebBOARD/67057225CC780623852578F10059533D/$File/EPA-SAB-11-013-unsigned.pdf)

U.S. EPA, 2002. Onsite wastewater treatment systems manual. EPA/625/R-00/008. U.S. Environmental Protection Agency, Office of Water, Office of Research and Development. www.epa.gov/nrmrl/pubs/625r00008/html/625R00008.htm

U.S. Weather Bureau, 1965. Mean annual precipitation 1930-1957, State of Washington: Portland, Oregon. U.S. Soil Conservation Service, map M-4430.

van der Schans, M. L., T. Harter, A. Leijnse, M.C. Matthews, R.D. Meyer. Characterizing sources of nitrate leaching from an irrigated dairy farm in Merced County, California. J. of Contaminant Hydrology. Vol. 110(1-2): 9-21.

van Es, H.M. and R.R. Schindelbeck, 2006. Effect of manure application timing, crop, and soil type on nitrate leaching. Journal of Environmental Quality, Vol. 35, p. 670-679.

VanWieringen, L. and J. Harrison, 2009. Fate of manure nitrogen applied for grass silage production. Final report submitted by Washington State University Livestock Nutrient Program, July 2009, 28 pages.

Verloop, J. , L.J.M. Boumans, H. van Keulen, J. Oenema, G.J. Hilhorst, H.F.M. Aarts and L.B.J. Sebek, 2006. Reducing nitrate leaching to groundwater in an intensive dairy farming system. Nutrient Cycling in Agroecosystems, Volume 74, p.59–74.

Viers, J.H., D. Liptzin, T.S. Rosenstock, V.B. Jensen, A.D. Hollander, A. McNally, A.M. King, G. Kourakos, E.M. Lopez, N. De La Mora, A. Fryjoff-Hung, K.N. Dzurella, H. Canada, S. Laybourne, C. McKenney, J. Darby, J.F. Quinn, and T. Harter, 2012. Nitrogen sources and loading to groundwater. Technical Report 2. Assessing Nitrate in California's Drinking Water. Report for the State Water Resources Control board Report to the Legislature. 280 p. + appendices.

Ward, M. H., T. M. deKok, P. Levallois, J. Brender, G. Gulis, B. T. Nolan, and J. VanDerslice, 2005. Workgroup Report: Drinking-Water Nitrate and Health—Recent Findings and Research Needs. Environmental Health Perspectives. Volume 113, Issue 11, pages 1607–1614.

Ward, W., 2001. Stream sampling protocols for the Environmental Monitoring and Trends Section, Washington State Department of Ecology, Olympia, WA, Publication No. 01-030036.

Washington State Department of Ecology, 2008. Manchester Environmental Laboratory Lab User's Manual, 9th Edition. 194 p. <http://aww.ecologydev/programs/eap/forms/labmanual.pdf>

Wassenaar, L. I., J. Hendry, and N Harrington, 2006. Decadal geochemical and isotopic trends for nitrate in a Transboundary aquifer and implications for agricultural beneficial management practices. *Environmental Science and Technology*, Volume 40, p. 4626-4632.

Weyer, P. J., J. R. Cerhan, B. C. Kross, G. R. Hallberg, J. Kantamneni, G. Breuer, M. P. Jones, W zheng, and C. F. Lynch, 2001. Municipal drinking water nitrate level and cancer risk in older women: The Iowa women's health study. *Epidemiology*, Volume 11, Issue 3, pages 327-338.

Whatcom Farm Friends, 2012. <http://www.wcfarmfriends.com/go/doc/1579/177780/>

Whitmore, A.P., N.J. Bradbury, and P.A. Johnsons, 1992. Potential contribution of ploughed grassland to nitrate leaching. *Agriculture, Ecosystems, and Environment*. Volume 39, p. 221-233.

Zebarth, B. J., 2012. Agriculture and Agri-Food Research Canada. Personal communication.

Zebarth, B.J., J.W. Paul, and R. van Kleeck, , 1999. The effect of nitrogen management in agricultural production on water and air quality: evaluation on a regional scale. *Agriculture, Ecosystems, and Environment*, Vol. 72(1), p. 35-52.

Zebarth, B.J., B. Hii, H. Liebscher, K. Chipperfield, J.W. Paul, G. Grove, and S. Szeto, 1998. Agricultural land use practices and nitrate contamination in the Abbotsford Aquifer, British Columbia, Canada. *Agriculture Ecosystem Environment*. 69:99-112.

Zebarth, B.J., Paul, J.W., Schmidt, O., McDougall, R., 1996. Influence of the time and rate of liquid manure application on yield and nitrogen utilization of silage corn in south coastal British Columbia. *Canadian Journal of Soil Science*, Volume 76, p. 153-164.

Zebarth, B.J and J.W. Paul, 1995. Impact of changes on agricultural land use on nitrogen loading to the Abbotsford Aquifer. Pacific Agricultural Research Centre (Agassiz, B.C.). p. 6 *In* Technical Report 119. Agriculture and Agri-Food Canada, Agassiz, B.C.

Zhao, H., X. Zhang, S. Xu, X. Zhao, Z. Xie, and Q. Wang, 2010. Effect of freezing on soil nitrogen mineralization under different plant communities in a semi-arid area during a non-growing season. *Applied Soil Ecology*, Volume 45, p. 187-192.

Appendices

Appendix A. Glossary, Acronyms, and Abbreviations

Glossary

Aerobic: In terms of liquid water, the state that contains oxygen at a measurable level.

Anaerobic: In terms of liquid water, devoid of oxygen at a measurable level.

Coefficient of curvature: xx

Effective grain size: xx

Hydraulic conductivity: Rate at which water moves through a material at a unit gradient and depends on the size and arrangement of the pores between the particles.

Maximum Contaminant Level: A regulatory limit set by the Environmental Protection Agency (EPA) for contaminants in drinking water. If an MCL is exceeded, regulatory action is required under the Safe Drinking Water Act.

Methemoglobinemia: A serious health condition that reduces the ability of red blood cells to carry oxygen that can result from exposure to high levels of nitrate. In most adults and children, these red blood cells rapidly return to normal. However, in infants it can take much longer for the blood cells to return to normal. Infants who drink water with high levels of nitrate (or eat foods made with nitrate-contaminated water) may develop a serious health condition due to the lack of oxygen and call “blue-baby syndrome.”

Recharge: (noun) The amount of water entering the saturated zone at the water-table surface over a period of time.

Specific capacity: A measure of the productivity of a well estimated by measuring the pumping rate (yield) and dividing by the change in the height of water in the well (drawdown)

Uniformity coefficient: xx

Acronyms and Abbreviations

BGS	Below ground surface
BMP	Best management practices
DO	Dissolved oxygen
DOC	Dissolved organic carbon
Ecology	Washington State Department of Ecology
I.D.	Inside diameter
MCL	Maximum Contaminant Level
MEL	Manchester Environmental Laboratory

O.D.	Outside diameter
PVC	Polyvinyl chloride
RPD	Relative percent difference
SBA	Sumas-Blaine Aquifer
SD	Standard deviation
TOC	Total organic carbon
USGS	U.S. Geological Survey
WAC	Washington Administrative Code

Units of Measurement

°C	degrees centigrade
dw	dry weight
ft	feet
in	inches
kg	kilograms, a unit of mass equal to 1,000 grams.
km	kilometer, a unit of length equal to 1,000 meters.
mm	millimeter
mg/kg	milligrams per kilogram (parts per million)
mg/L	milligrams per liter (parts per million)
mL	milliliters
s.u.	standard units
µg/L	micrograms per liter (parts per billion)
µmhos/cm	micromhos per centimeter, a unit of conductivity

Geologic Log

Unique Ecology Well ID Tag No AKG-722

Site Address H St. Rd.

City Lynden County: whatcom

Location 1/4-1/4 1/4 Sec 1 Twn R EWM circle or WWM

Lat/Long (S, T, R) Lat Deg Lat Min/Sec

Long Deg Long Min/Sec

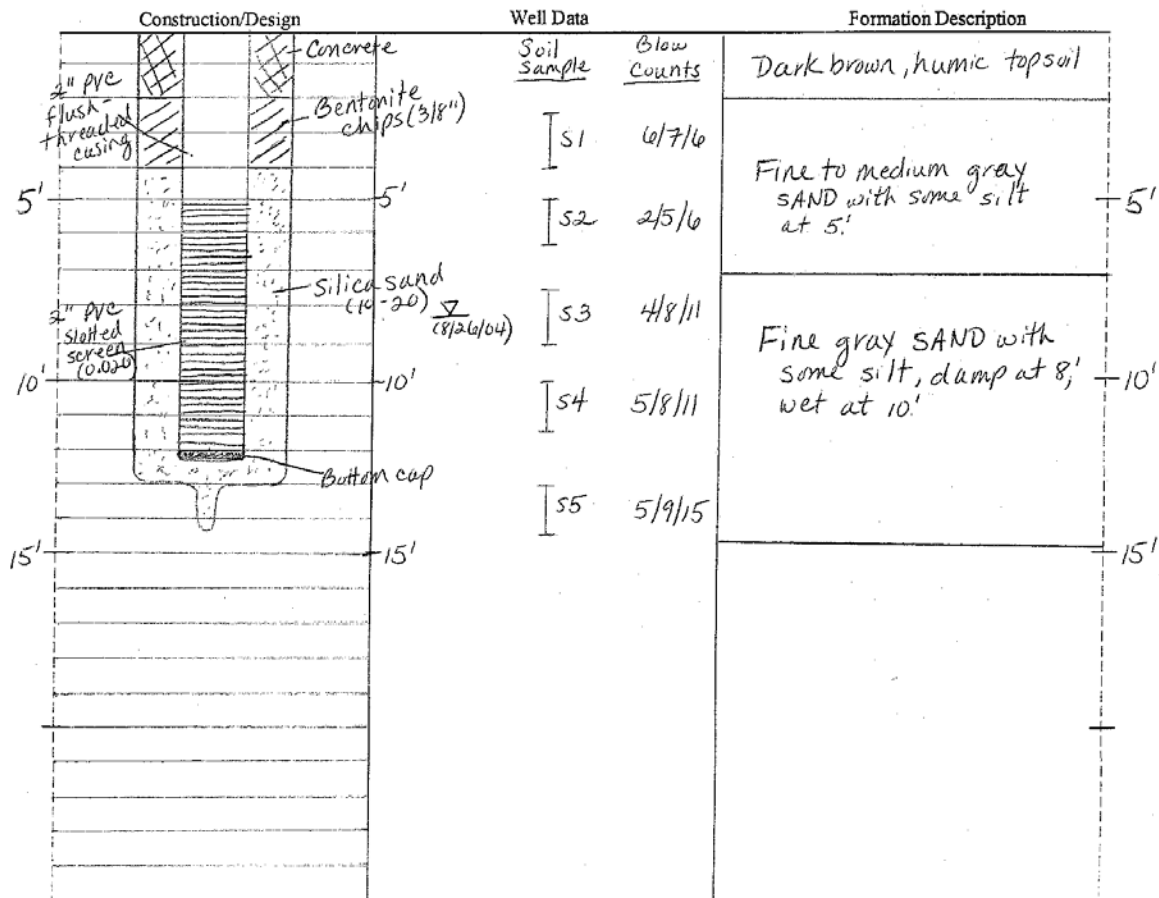
Cased or Uncased Diameter Static Level 8.4'

Date 8/25/04

Driller Holt Drilling, Milton, WA

Hydrogeologist Barbara Carey, Ecology

Drilling Method: Hollow-stem auger
Ground Surface Elevation: 126.80'
(from USGS 1:24,000 map, relative to AKG-721)



Geologic Log

Unique Ecology Well ID Tag No AKG-723

Site Address H St. Rd.

City Lynden County: Whatcom

Location 1/4-1/4 1/4 Sec 1 Twn 1 R 1 EWM circle or one

Lat/Long (s, t, r) Lat Deg 48 Lat Min/Sec 59/465 WWM

Long Deg 122 Long Min/Sec 30/365

Cased or Uncased Diameter Static Level 9.7'

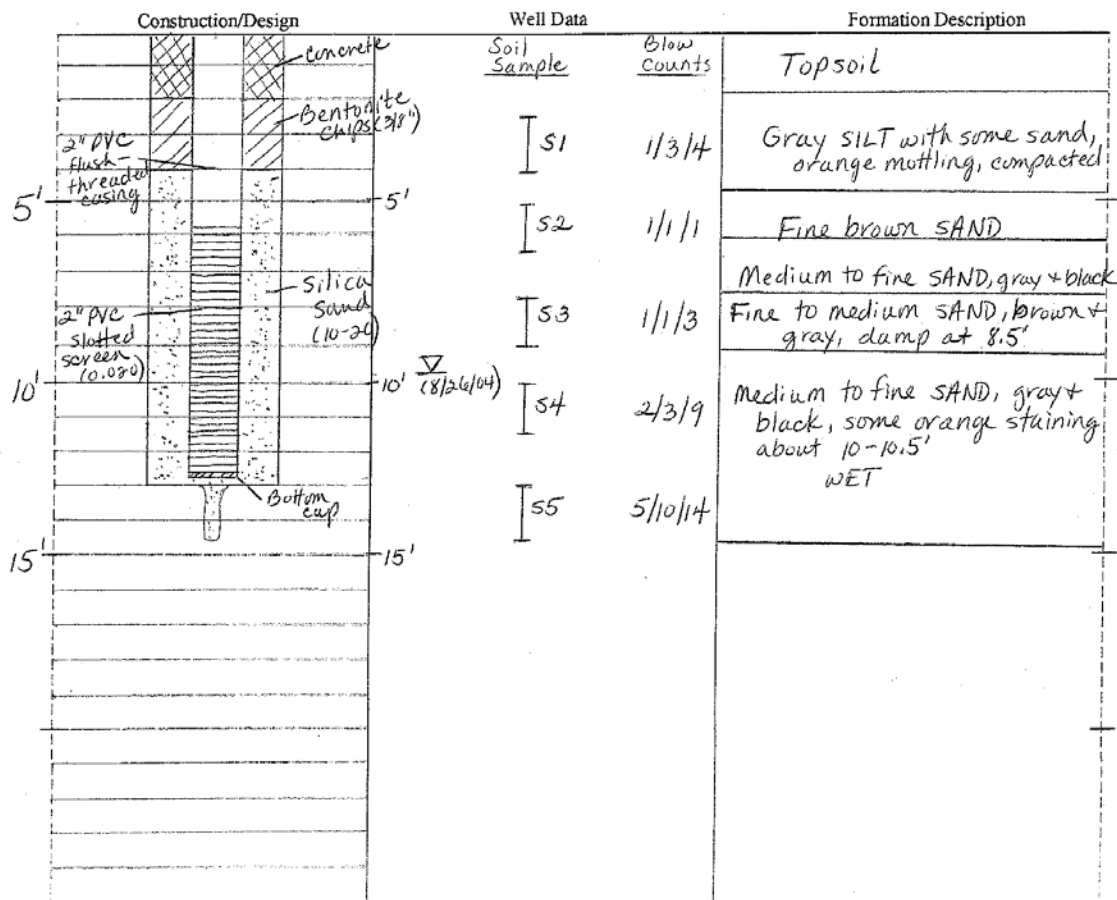
Date 8/25/04

Driller Holt Drilling, Milton, WA

Hydrogeologist Barbara Carey, Ecology

Drilling Method: Hollow-stem auger

Ground surface elevation: 126.84'
(From USGS 1:24,000 map, relative to AKG-721.)



Geologic Log

Unique Ecology Well ID Tag No AKG-724

Site Address H St. Rd.

City Lynden County: Whatcom

Location 1/4-1/4 1/4 Sec. 1 Twn. R. EWM circle or one

Lat/Long (s, l, r) Lat Deg 48 Lat Min/Sec 59/447 WWM

Long Deg 122 Long Min/Sec 30/303

Cased or Uncased Diameter 2" Static Level 8.25'

Date 8/26/04

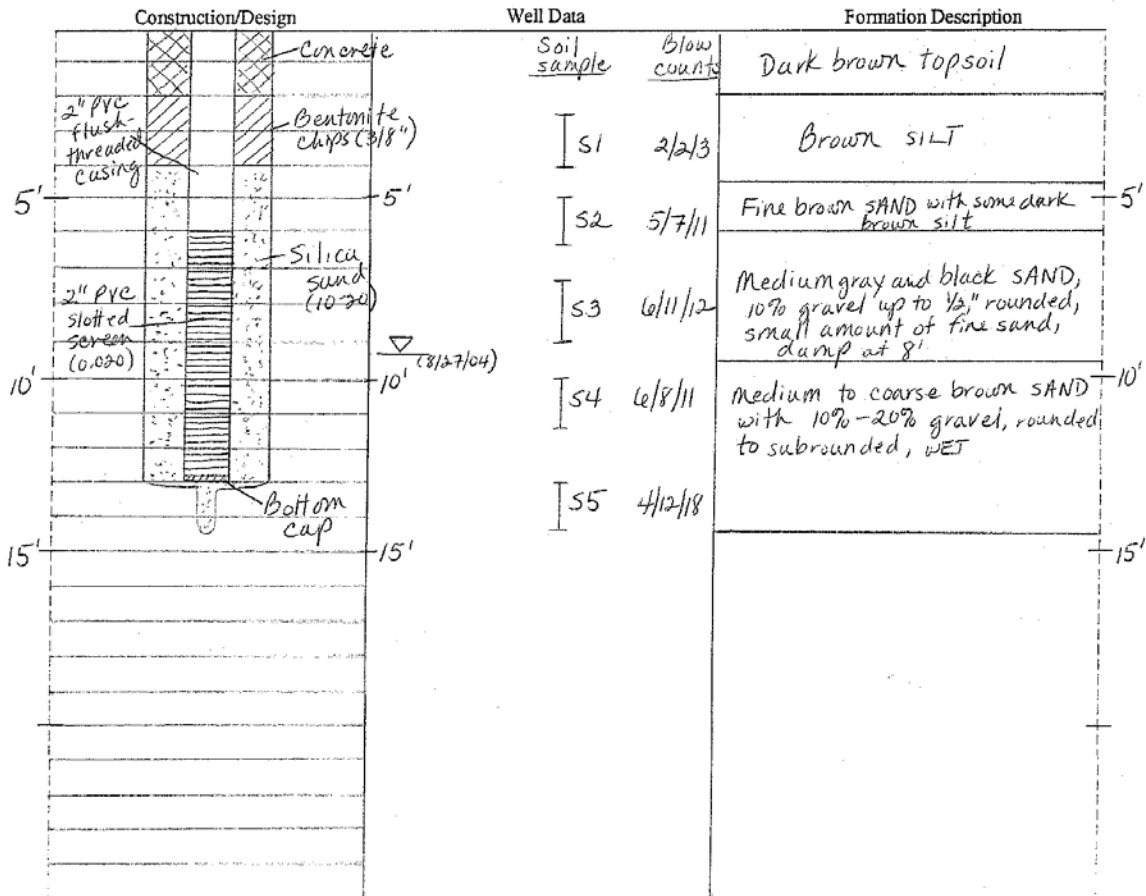
Driller Holt Drilling

Hydrogeologist Barbara Carey

Drilling Method: Hollow Stem Auger

Ground Surface Elevation: 124.97'

(From USGS 1:24,000 map, relative to AKG-721.)



Geologic Log

Unique Ecology Well ID Tag No AKG-725

Site Address H St. Rd.

City Lynden County: Whatcom

Location 1/4 1/4 1/4 Sec. 1 Twn 1 R. 1 EWM circle or one

Lat/Long (s, l, r) Lat Deg 48 Lat Min/Sec 59 ^{WWM} 56

Long Deg 122 Long Min/Sec 30 36 4

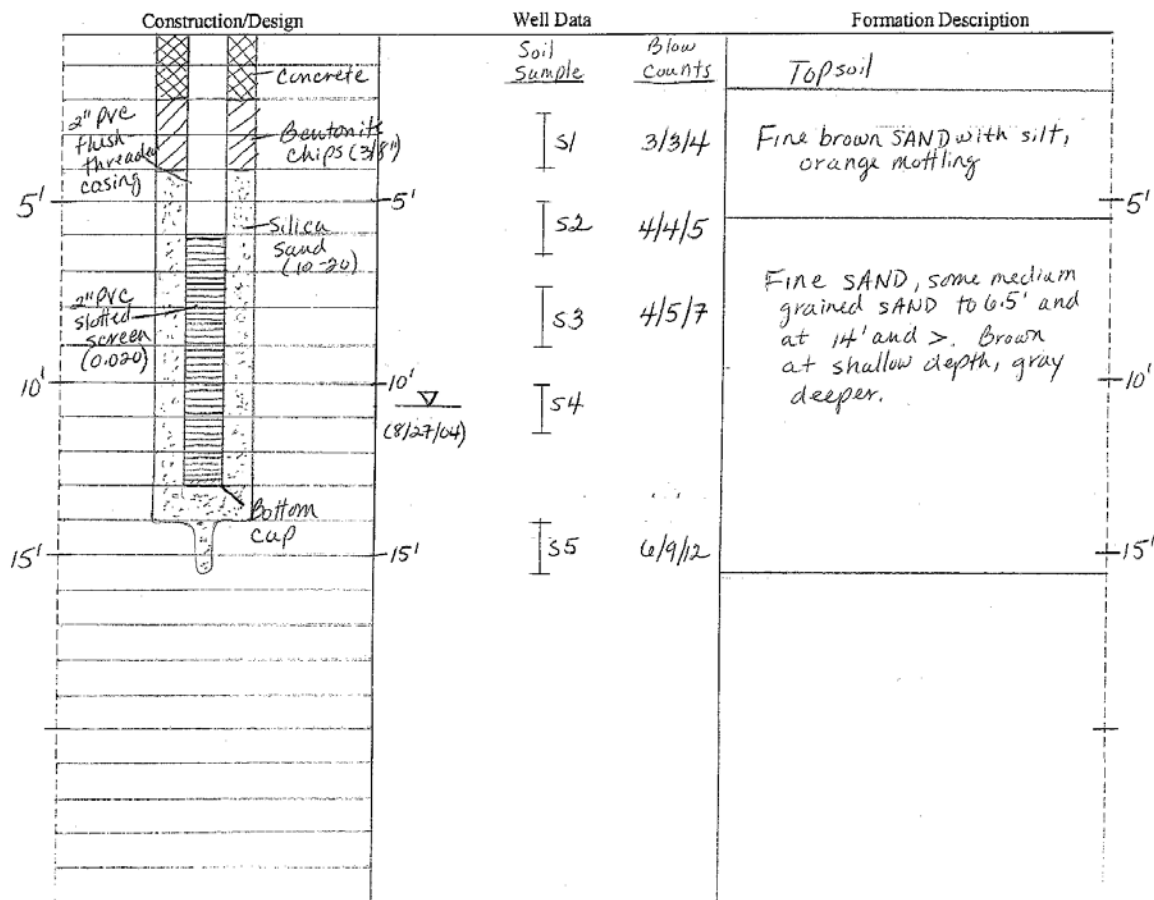
Cased or Uncased Diameter 2" Static Level 10.58'

Date 8/26/04

Driller Holt Drilling

Hydrogeologist Barbara Carey

Drilling Method: Hollow-Stem Auger
Ground Surface Elevation: 128.73'
(From USGS 1:24,000 map, relative to AKG-721.)



Geologic Log

Unique Ecology Well ID Tag No AKG-726

Site Address # St. Rd.

City Lynden County: Whatcom

Location 1/4 1/4 1/4 Sec 1 Twn R EWM circle or one

Lat/Long (s, t, r) Lat Deg 48 Lat Min/Sec 59/512 WWM

Long Deg 122 Long Min/Sec 30/364

Cased or Uncased Diameter 2" Static Level 10.61'

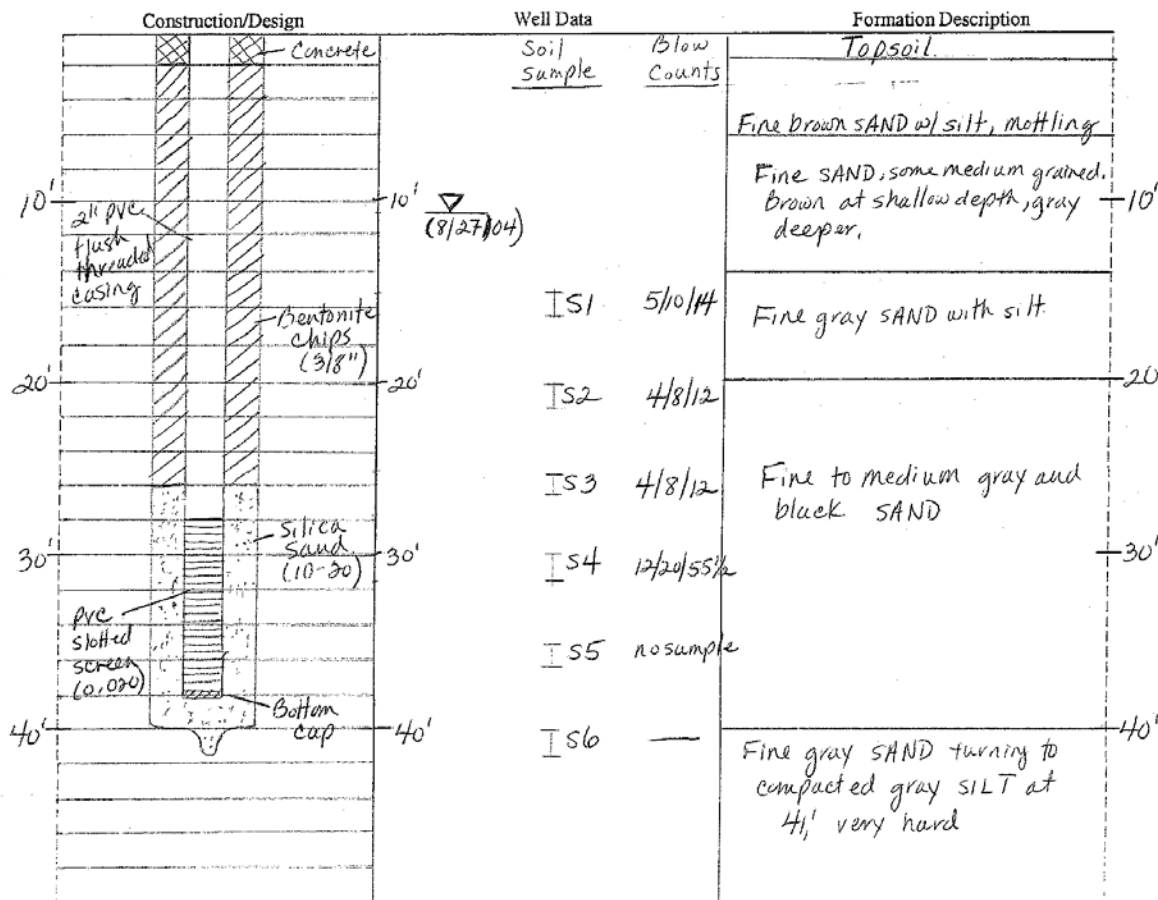
Date 8/26/04

Driller Holt Drilling

Hydrogeologist Barbara Carey

Drilling method: Hollow-stem Auger

Ground Surface Elevation: 128.68'
(from USGS 1:24,000 map, relative to AKG-721)



Geologic Log

Unique Ecology Well ID Tag No AKG-727

Site Address H St. Rd.

City Lynden County: Whatcom

Location 1/4-1/4 1/4 Sec. Ywn R EWM circle or one WWM

Lat/Long (s, t, r) Lat Deg Lat Min/Sec

Long Deg Long Min/Sec

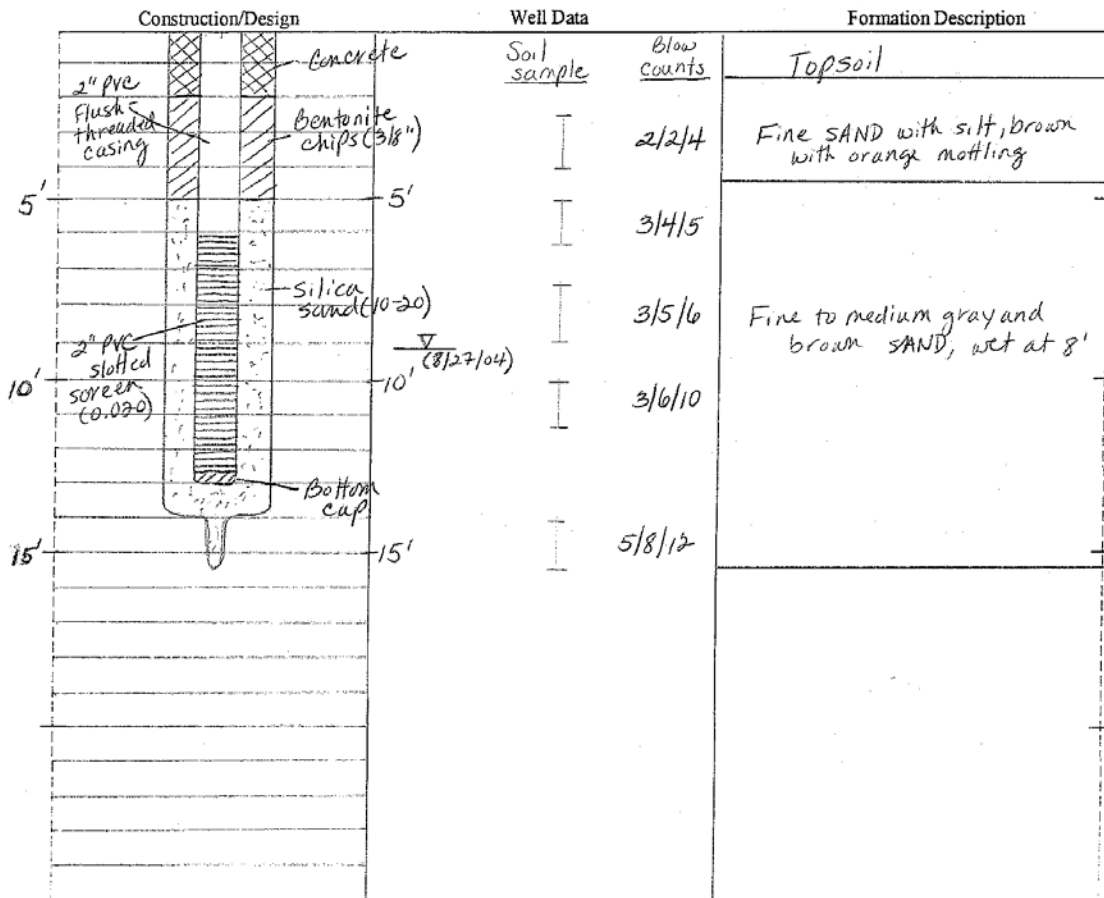
Cased or Uncased Diameter 2" Static Level 9.18'

Date 8/26/04

Driller Holt Drilling

Hydrogeologist Barbara Carey

well drilling method: Hollow-stem auger
Ground surface elevation: 127.43'
(from USGS 1:24,000 map, relative to AKG-721.)



Page of

ECY 050-12 (Rev 2-01)


(Nooksack 2/Report/drillers logs2.pdf)

Drillers logs for private wells just north of the study site, ALQ013 and APM737.

41-2E 36N

The Department of Ecology does NOT Warranty the Data and/or the Information on this Well Report.

155055 Please print, sign and return to the Department of Ecology



Water Well Report

Original - Ecology, 1st copy - owner, 2nd copy - driller

Construction/Decommission

☒ Construction
☐ Decommission *ORIGINAL INSTALLATION Notice of Intent Number*

PROPOSED USE: ☒ Domestic ☐ Industrial ☐ Municipal
☐ DeWater ☐ Irrigation ☐ Test Well ☐ Other

TYPE OF WORK: Owner's number of well (if more than one)
☒ New well ☐ Reconditioned *Method:* ☐ Dug ☐ Bored ☐ Driven
☐ Deepened ☐ Cable ☒ Rotary ☐ Jetted

DIMENSIONS: Diameter of well 6 inches, drilled 38 ft.
 Depth of completed well 34 ft.

CONSTRUCTION DETAILS
 Casing: ☒ Welded 6 " Diam. from 20 ft. to 29 ft.
 Installed: ☐ Liner installed " Diam. from " ft. to " ft.
☐ Threaded " Diam. from " ft. to " ft.

Perforations: ☐ Yes ☒ No
 Type of perforator used _____
 SIZE of perfor. _____ in. by _____ in. and no. of perfor. _____ from _____ ft. to _____ ft.

Screens: ☒ Yes ☐ No *K-Pac Location*
 Manufacturer's Name _____
 Type _____
 Diam. 6 Slot size 0.02 from 29 ft. to 34 ft.
 Diam. _____ Slot size _____ from _____ ft. to _____ ft.

Gravel/Filter packed: ☐ Yes ☒ No ☐ Size of gravel/sand _____ ft. to _____ ft.
 Materials placed from _____ ft. to _____ ft.

Surface Seal: ☒ Yes ☐ No To what depth? 18 ft.
 Material used in seal Bentonite
 Did any strata contain unusable water? Yes (No)
 Type of water? _____ Depth of strata _____
 Method of sealing strata off _____

PUMP: Manufacturer's Name _____
 Type: _____ H.P.

WATER LEVELS: Land-surface elevation above mean sea level _____ ft.
 Static level 11 ft. below top of well Date 9/22/04
 Artesian pressure _____ lbs. per square inch Date _____
 Artesian water is controlled by _____ (cap, valve, etc.)

WELL TESTS: Drawdown is amount water level is lowered below static level
 Was a pump test made? ☒ Yes ☐ No If yes, by whom? BCW
 Yield: 17 gal/min. with _____ ft. drawdown after _____ hrs.
 Yield: _____ gal/min. with _____ ft. drawdown after _____ hrs.
 Yield: _____ gal/min. with _____ ft. drawdown after _____ hrs.

Recovery data (time taken to zero when pump turned off) (water level measured from well top to water level)

Time	Water Level	Time	Water Level	Time	Water Level

 Date of test _____
 Boiler test _____ gal/min. with _____ ft. drawdown after _____ hrs.
 Airtest 20 gal/min. with stem set at 33 ft. for 1 hrs.
 Artesian flow _____ g.p.m. Date _____
 Temperature of water _____ Was a chemical analysis made? ☐ Yes ☒ No

WELL CONSTRUCTION CERTIFICATION: I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief.

Driller/Engineer/Trainee Name (Print) Bill Cochran
 Driller/Engineer/Trainee Signature [Signature]
 Driller or trainee License No. 0005

IF TRAINEE:
 Driller's Licensed No. _____
 Driller's Signature _____

Drilling Company BCW Well Drilling
 Address 880 Kelly
 City, State, Zip Bellevue WA
 Contractor's Registration No. BCWELD097142 9/15/04
 Ecology is an Equal Opportunity Employer. ECY 050-1-20 (Rev 2/03)

Current
 Notice of Intent No. WE 02597
 Unique Ecology Well ID Tag No. ALQ 013
 Water Right Permit No. _____
 Property Owner Name _____
 Well Street Address 490 H St
 City Lynden County Whatcom
 Location 2nd 1/4 Sec 36 Twp 42 R 2 EWM ☒ circle or WWM ☐ one

Lat/Long (s, t, r) _____ Lat Deg _____ Lat Min/Sec _____
 still REQUIRED) Long Deg _____ Long Min/Sec _____
 Tax Parcel No. 410 23 6030 020

CONSTRUCTION OR DECOMMISSION PROCEDURE
 Formation: Describe by color, character, size of material and structure, and the kind and nature of the material in each stratum penetrated, with at least one entry for each change of information indicate all water encountered. (USE ADDITIONAL SHEETS IF NECESSARY.)

MATERIAL	FROM	TO
Topsoil	0	1
Brown clay	1	4
Brown Sand	4	6
Gray Sand 420 @ 10	6	28
Red gravel sand	28	33
Gray clay	33	34

RECEIVED
SEP 21 2004
DEPT OF ECOLOGY

Start Date 9/19/04 Completed Date 9/22/04

WASHINGTON STATE

Original & 1st copy – Ecology, 2nd copy – owner, 3rd copy – driller

ECOLOGY
Construction/Decommission ("x" in circle)

Construction

☐ Decommission *ORIGINAL INSTALLATION* Notice
of Intent Number _____

CURRENT

Notice of Intent No. 218025

Unique Ecology Well ID Tag No. APm 737

Water Right Permit No.

Property Owner Name

Well Street Address 430 H. STREET

City LYNDEN County WITATUM

Location SW 1/4-1/4 SW 1/4 Sec 36 Twn 41N R 092E Wm circled

Lat/Long (s, t, r) Lat Deg _____ Lat Min/Sec _____

Still **REQUIRED**) Long Deg Long Min/Sec

Tax Parcel No. 410236 090020 0000

CONSTRUCTION OR DECOMMISSION PROCEDURE

Formation: Describe by color, character, size of material and structure, and the kind and nature of the material in each stratum penetrated, with at least one entry for each change of information. (USE ADDITIONAL SHEETS IF NECESSARY.)

MATERIAL	FROM	TO
TOP SOIL	0'	1'
HARD BROWN CLAY	1'	8'
MEDIUM - COARSE GREY SAND	8'	25'
GRAVEL / MEDIUM-COARSE GREY SAND / WATER	25'	34'
BLUE CLAY	34'	38'
RECEIVED		
APR 19 2007		
SEP 28 2007		
Water Resources Program Department of Ecology		
Start Date 10/19/2006	Completed Date 10/20/2006	

Start Date 10/19/2006

Completed Date 10/20/2006

WELL CONSTRUCTION CERTIFICATION: I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief.

☐ Driller ☐ Engineer ☒ Trainee Name (Print) JERRY L. PETERSON

Driller/Engineer/Trainee Signature

Driller or trainee License No. 2776T**TRAINEE**

IF TRAINEE, Driller's Lice

Driller's Signature _____

Drilling Company LIVERMORE & SON, LLC

Address 5355 HOMESTEADER RD.

City, State, Zip DEMING, WA. 98244

Contractor's

Registration No. LIVERSL981RC Date 10/20/2006

Ecology is an Equal Opportunity Employer.

Ecology is an Equal Opportunity Employer.

ECY 050-1-20 (Rev 3/05)

The Department of Ecology does NOT warranty the Data and/or Information on this Well Report.

Appendix C. List of Analytes Measured in Groundwater, Soil, Manure, Grass, and Irrigation Water.

Groundwater samples for laboratory analysis were filtered in the field except for the deep well, AKG726, which were not filtered.

(My Doc's/ Nooksack 2/Report/Final Report 2010/method sect_list of analytes.xls)

Analyte	Matrix ¹	Frequency
<i>Field</i>		
Groundwater Temperature	G, S	Monthly (Summer every 6 weeks)
pH	G	Monthly (Summer every 6 weeks)
Specific Conductivity	G	Monthly (Summer every 6 weeks)
Dissolved Oxygen	G	Monthly (Summer every 6 weeks)
Soil Temperature	S	Monthly (Weekly August-November)
Soil Moisture	S	Monthly (Weekly August-November)
<i>Laboratory</i>		
Ammonium-N	G, M, I	G--Monthly (Summer every 6 weeks) M--Each time manure applied I--Each time irrigation water applied
Nitrate+Nitrite-N	G, I	G--Monthly (Summer every 6 weeks) I--Each time irrigation water applied
Nitrate	S	Weekly August-November, otherwise monthly
Total Persulfate N	G, I	G--Monthly (Summer every 6 weeks) I--Each time irrigation water applied
Total Kjeldahl N	M	Each time manure applied
Ortho Phosphate P	G	Monthly (Summer every 6 weeks)--(2004-2006)
Total Dissolved Phosphorus P	G, S, M	G--Monthly (Summer every 6 weeks) S-- Annually M-- Each time manure applied
Chloride	G, M	G--Monthly (Summer every 6 weeks) M-- Each time manure applied
Total Dissolved Solids	G	Monthly (Summer every 6 weeks)
Total Organic Carbon	G	G--Monthly (Summer every 6 weeks)
Grain size	S	One time for drilling samples
Dry Matter	Gs	Each time grass crop harvested
Crude Protein (N)	Gs	Each time grass crop harvested

¹ Matrix codes: G=Groundwater, S=Soil, M=Manure, Gs=Grass, I=Irrigation water.

Appendix D. Manure Sampling Standard Operating Procedures (SOP).

Sampling Events (between 4 and 6 per year)

- Late winter/early spring
- Typically after each grass cutting

Items needed to manure sample

- Clean 5-gallon bucket
- Rain suit and boots
- Clean ladle
- Nalgene containers
- Tape and permanent pen
- Log book and pen
- Agros Meter
- Warm water
- Camera

Sampling Methods

- Call the producer to schedule sampling during each manure application .
- Take sample at the discharge of the equipment putting the manure on the field.
- Fill a 5-gallon bucket about $\frac{3}{4}$ of the way full with sample.
- Label 4 Nalgene containers. Use 2 log numbers for duplicate samples. Label 2 Nalgene containers with 1 log number (DOE M1 in the example) and the other 2 Nalgene containers with another log number (DOE M2).
- Record log numbers in the log book, with sampling date, manure application equipment, and Agros Meter reading for ammonia-N.
- Stir the manure in the bucket vigorously with the ladle, and ladle the manure into the Nalgene containers while the manure is still moving.
- Fill the Nalgene containers about 80% full. (This gives room for the liquid to expand when it freezes).
- Place manure samples on ice and transport to a freezer as soon as possible.

Sampling Ammonia with an Agros Meter

- Take a subsample of the manure in the 5-gallon bucket and conduct an Agros Meter analysis for ammonia following the manufacturer's instructions. Use 80⁰ to 90⁰ F water for the analysis, and record the temperature of the manure-water mix in the cylinder prior to adding chemicals.

Processing Manure Samples for the Contract Lab

-Each manure sample is analyzed for solids, total N, ammonia-N, phosphate, and potash concentration.

-Prior to shipment type a requisition to the lab with the information needed, put in a Ziploc bag, and placed on top of the Styrofoam cooler (inside a cardboard box).

Appendix E. Irrigation Water Sampling Standard Operating Procedures (SOP).

Sampling Events (2 to 4 times per year)

-Late spring through late summer

Items needed

- Three 5-gallon buckets with sand in the bottom (used to hold the empty 5-gallon buckets upright while water is going into them)
- 3 clean 5-gallon buckets
- Graduated cylinder
- Tape, timer, pen, and paper

Sampling Methods

-Keep in contact with the producer to schedule sampling for the each irrigation event.

-Carry three 5-gallon buckets with sand and the 3 clean 5-gallon buckets into the field where irrigation water will be applied. Place a clean bucket inside of a bucket of sand. The bucket should be in the middle of the area the water is being applied. Place it close to the irrigation hose (but far enough away that the gun will not hit it as it is moving). Place another bucket with sand and clean bucket inside about $\frac{3}{4}$ of the way across the length of the irrigation water spray to the right of the bucket that was placed in the middle. Place the last bucket with sand and clean bucket about $\frac{3}{4}$ of the way across the length of the irrigation water spray to the left of the bucket that was placed in the middle.

-These buckets should be in a straight line with each other once they are set out. They should run horizontal to the irrigation water spray. Make sure the water is not hitting them when they are set out (so that you do not miss any of the water that could potentially go into the buckets). Also, make sure that the buckets are far enough away from the reel that when the gun is pulled in all the way, it won't sit there and fill the buckets before it is turned off.

-After irrigation water has been collected into the buckets, retrieve all the buckets.

-Pour the water into a 1,000-ml graduated cylinder, and record the amount (usually between 7,000 and 10,000 ml). **Note: Do not discard the water after you fill the graduated cylinder. You will need it for water samples.**

-Label 4 nalgene containers. Use 2 log numbers (one for the sample and one for the duplicate).

-Label 2 Nalgene containers with 1 log number (DOE I1 in the example) and the other 2 nalgene containers with another log number (DOE I2).

-Record log numbers in the log book, with sampling date and amount of irrigation water applied.

-Stir the irrigation water vigorously with the ladle, and ladle the irrigation water into the Nalgene containers while the irrigation water is still moving.

-Fill the Nalgene containers about 80% full. (This gives room for the liquid to expand when it freezes).

-Place irrigation water samples on ice and transport to freezer as soon as possible.

-Send iced irrigation water samples to the Manchester Environmental Laboratory.

Appendix F. Grass Sampling Standard Operating Procedures (SOP).

Sampling Events (approximately 5 per year)

-Late spring through fall

Items needed to grass sample

- 2 ft by 2 ft PVC pipe square
- Hedge trimmer
- Gas and oil mix
- Pliers to get gas lid off of hedge trimmer
- Garbage bags
- Rubber bands, labels, and permanent pen
- Log book and pen
- GPS and extra set of batteries
- Scale, tote, and garbage bag (for tare) to weigh each individual grass sample

Sampling Methods

- Keep in contact with the producer to schedule grass sampling just prior to each cutting.
- Label 10 manila labels (one for each sampling location) with DOE log number using a sharpie.
- Five grass samples from randomly selected locations in the field will be composited in the laboratory after wet weight and dry weight measurements. The sample procedure will be done to another 5 subsamples for a duplicate sample. Samples will be collected at about the same location each time.
- Attach a rubber band to each label. The rubber band will be used to attach the label to the garbage bag holding the grass sample.
- Take the 2-foot by 2-foot PVC pipe square, hedge trimmer, GPS, GPS coordinates, 5 garbage bags, 5 labels with rubber bands, and camera (optional).
- At each GPS location, place the PVC pipe square in the grass as close to the ground as you can push it. Use the hedge trimmers to cut the grass. Place the grass in a clean garbage bag. Label the bag with a GPS label. Place the garbage bag (with grass) into another garbage bag. Proceed to the next GPS location.

GPS Locations for Grass Samples

Processing Grass Samples for WSU Puyallup

- Transport grass samples to a freezer.
- Prior to placing the grass samples in a freezer, weigh them and record a weight in pounds in the log book.

-The entire grass sample will go to WSU Puyallup for dry weight and nutrient analyses.
Contact WSU Puyallup to coordinate shipment time.

Appendix G. Soil Sampling Standard Operating Procedures (SOP).

Sampling Events (25 per year)

- Monthly from January through July and December
- Weekly August through November

Items needed

- 1-foot soil probe
- Screwdriver to dislodge soil from the soil probe
- 2 buckets
- 2 – 6-inch soil temperature probes
- Log book and pen
- Ice bags and permanent marker
- GPS and extra set of batteries
- GPS locations
- Camera

Sampling Methods

Soil Temperature

- Set one bucket as a marker for the 6-inch temperature probe.
- Insert the temperature probe in the ground near the marker bucket and leave it while collecting soil samples. Read the probe and record the temperature in the log book after collecting soil samples.
- The temperature probes are fairly delicate, therefore, I insert 2 probes at each location to make sure I am getting similar readings. When a variation between the readings occurs, discard the broken one (it's usually pretty obvious), and replace it with a new probe. I usually go through a few probes each year.

Duplicate sampling methods

- Collect 15 one- foot soil cores into a clean bucket at the GPS sites randomly chosen across the field. The same 15 sites are sampled each time.
- Discard the loose crop or manure residue at the top of the core before placing the core in the bucket.
- Mix the soil cores in the bucket extensively until the majority of clumps are broken and the soil has been mixed thoroughly (this reduces variability in soil nitrate values between duplicates).

- Collect a second set of 15 one-foot cores (duplicate) into another clean bucket at another 15 GPS sites randomly chosen. The same second group of 15 sites is sampled each time.

GPS Locations in the Field for Soil Samples

Splitting Soil Samples

- Split the mixed composite sample into 3 subsamples and place into 3 clean plastic bags: one sample for the contract laboratory, one for archival at WSU Puyallup, and one annually for a laboratory split replicate.
- Place all samples in a cooler with ice packs and transport to a freezer within one hour of sampling.

Processing Soil Samples for Contract Lab

- Assign each soil sample a log number for nitrate analysis. Send soil samples to contract lab about once per month.
- Once each year (April samples) do a complete soil analysis (??) including Bray P.

Processing Soil Samples for WSU Puyallup

- The remaining splits of the soil samples are periodically sent to WSU Puyallup for dry matter analysis.
- Type a memo and e-mail it to WSU Puyallup indicating the soil sample log numbers, number of samples, number of packages being shipped, estimated arrival date, and request for soil analysis for Dry Matter.
- FedEx samples to WSU Puyallup.

Appendix H. Monitoring Well Construction Information.

Measurements are in feet.

Well ID	Latitude N	Longitude W	Well Elevation ¹ (TOC ²)	Well Depth (feet below TOC ²)	Open interval (feet below TOC ²)
AKG721	48.99344	122.50603	134.00	12.8	5.8-12.8
AKG722	48.99227	122.50377	130.80	12.1	5.1-12.1
AKG723	48.99177	122.50593	130.84	12.7	5.7-12.7
AKG724	48.99107	122.50505	128.97	13.0	6.0-13.0
AKG725	48.99208	122.50726	132.73	13.0	6.0-13.0
AKG726	48.99209	122.50726	132.68	38	28-38
AKG727	48.99318	122.50518	131.43	12.9	5.9-12.9

¹Elevation of the top of casing for AKG721 was established as an arbitrary datum and assigned a value of 134.00 feet (NAVD88) from a 10- meter Digital Elevation Model spatial coverage. Elevations of other wells were surveyed relative to AKG721 top of casing to an accuracy of 0.01 foot.

² Top of casing.

(...well construction_13.xlsx)

Appendix I. Equations Used in the Bradbury and Rothschild (1985) Method for Estimating Hydraulic Conductivity.

$$\text{Eq. 1} \quad T = \frac{Q}{4\pi(s_m - s_w)} \left[\ln \left(\frac{2.25Tt}{r_w^2 S} \right) + 2s_p \right]$$

$$\text{Eq. 2} \quad s_w = CQ^2$$

$$\text{Eq. 3} \quad s_p = \frac{1-L/b}{L/b} \left(\ln \frac{b}{r_w} - G(L/b) \right)$$

$$\text{Eq. 4} \quad G(L/b) = 2.948 - 7.363(L/b) + 11.447(L/b)^2 - 4.675(L/b)^3$$

where

b - aquifer thickness	s _m - measured drawdown
C - well loss coefficient	s _w - well loss
L - screen length	s _p - partial penetration parameter
Q - mean pumping rate	S - storativity
r _w - effective radius	T - transmissivity
	t - pumping duration

Appendix J. Removed

Appendix K. Quality Assurance Results

Groundwater

Field meters were calibrated at the start of each day according to the manufacturer's instructions. Duplicate field measurements were collected at one monitoring well during each sampling event to assess combined precision of field and lab results. After routine sampling at the duplicate well (initial samples), the pump was turned off for a few minutes before the well was again purged, field measurements repeated (duplicate samples), and water quality samples collected (duplicate samples). The results of the duplicate samples are shown in Table K.6.

The relative standard deviation of the duplicates (RSD) represents the standard deviation of the two duplicate samples (SD) divided by the mean and expressed as a percentage:

$$RSD = \frac{SD}{mean} \times 100$$

Table K.7 is a compilation of RSD results for each analyte. The mean RSD for temperature, pH, and conductivity was 0.6-1.4 %. The range of RSD values for these parameters was 0-7.2%. The RSD for DO, which was often in the 0-3 mg/L range, was 8.7%. The range of RSD values for DO was 0.2-48%. The lower measurement range for DO tended to amplify the RSD compared to the other parameters. In addition, DO results fluctuated during purging more so than other field parameters, probably due to greater variation in the groundwater than other parameters. Targets were not specified for field parameters in the QAPP (Carey, 2004).

Except for the deep well, AKG726, all samples were field-filtered (0.45 um) in-line. From the start of the study until July 7, 2005, samples for ammonia-N, nitrate+nitrite-N, TPN, total and ortho-phosphorus from AKG726 were filtered at MEL. Total P and TOC samples collected on August 17, 2005 at AKG726 were also filtered at MEL. All other samples collected on August 17, 2005 and thereafter at AKG726 were not filtered.

The mean relative standard deviation for nitrate+nitrite-N based on field duplicates was 4.6%, for chloride 2.7%, dissolved organic carbon 5.3%, total dissolved solids 2.7%, total persulfate nitrogen 3.9%, and total phosphorus 17%. These values represent the combined field and laboratory precision. The target precision for nutrients was 7%, and that for chloride and DOC was 10%. The target was met for the mean RSD's of all parameters except total phosphorus. Individual RSD values over 20% are qualified as estimates in Appendix Table S.1.

During six sampling events in 2008, a blank sample of de-ionized water from MEL was collected at the end of the day using the same silastic tubing on the peristaltic pump as was used for monitoring well samples. Results of blank samples were used to evaluate potential cross-contamination from the silastic tubing (Table K.8).

Most of the blank results for the nitrogen series were below detection. On May 6, and June 19, 2008, both nitrate+nitrite-N and TPN were detected at concentrations roughly 1% of field values.

These results indicate that using the same piece of silastic tubing (new each sampling event) when purging and sampling each well was not a significant cross-contamination source.

Laboratory quality assurance consisted of duplicate blanks, duplicate samples, spiked samples and check (control) standards. MEL completed internal quality assurance review on all data sets. See Department of Ecology (2008 and 2007) for laboratory quality assurance methods and standard operations. All results are considered acceptable for use without qualification except for the following:

- September 21, 2004: TDS samples were analyzed outside acceptable holding time and are qualified as estimates (J).
- September 8, 2008: September 21, 2008: Chloride samples were analyzed outside acceptable holding time and are qualified as estimates (J).

Table K.1. Results of split manure samples.

Date	Sample ID	% Solids	Ammonia N (lb/ 1,000 gallons)	Total N (lb/ 1,000 gallons)
8/9/2005	DOE M9	1.69	8.51	11.05
8/9/2005	DOE M11	1.73	8.50	12.75
Relative Standard Deviation (%)		1.65	0.08	10.1*
8/31/2005	DOE M12	6.97	12.63	22.95
8/31/2005	DOE M14	6.63	10.64	23.80
Relative Standard Deviation (%)		3.54	12.1*	2.57
7/11/2006	DOE M17	2.37	4.46	11.05
7/11/2006	DOE M19	2.42	4.22	10.20
Relative Standard Deviation (%)		1.48	3.91	5.66
3/14/2007	DOE M23	3.65	6.02	14.45
3/14/2007	DOE M25	2.94	5.92	11.05
Relative Standard Deviation (%)		15.2*	1.18	18.9*
3/10/2008	DOE M33	4.28	6.55	19.92
3/10/2008	DOE M35	4.77	6.57	20.75
Relative Standard Deviation (%)		7.66	0.22	2.89
5/20/2008	DOE M37	2.85	5.76	--
5/20/2008	DOE M39	3.49	3.72	--
Relative Standard Deviation (%)		14.3*	30.4*	

* Relative standard deviation exceeds acceptable limit of 7%.
 (...Report/Final Report 2010/Manure_03_31_10.xlsx—splits tab)

Table K.2. Results of duplicate grass samples.

Sample	Date	Wet Weight	Average Wet Weight	Wet Weight Relative Std Deviation	Dry Matter	Average Dry Matter	Dry Weight Relative Std Deviation	Crude Protein	Average Crude Protein	Crude Protein Relative Std Deviation
		lbs	lbs	%	%	%	%	%	%	%
DOE-15	7/17/2005	1.55			19.32			14.2		
DOE-16	7/17/2005	0.95			26.22			14.2		
DOE-17	7/17/2005	1.70			18.31			14.2		
DOE-18	7/17/2005	1.40			19.06			14.2		
DOE-19	7/17/2005	2.20	1.56		21.8	20.9		14.2	14.2	
DOE-20	7/17/2005	1.30			19.72			15.1		
DOE-21	7/17/2005	1.40			20.56			15.1		
DOE-22	7/17/2005	1.10			21.96			15.1		
DOE-23	7/17/2005	1.55			17.76			15.1		
DOE-24	7/17/2005	1.50	1.37	9.17	20	20.0	3.25	15.1	15.1	4.34
DOE-25	8/25/2005	1.00			18.06			20.8		
DOE-26	8/25/2005	0.85			21.85			20.8		
DOE-27	8/25/2005	0.40			22.51			20.8		
DOE-28	8/25/2005	0.50			23.27			20.8		
DOE-29	8/25/2005	1.35	0.82		21.13	21.4		20.8	20.8	
DOE-30	8/25/2005	0.75			19.82			22.4		
DOE-31	8/25/2005	1.40			16.54			22.4		
DOE-32	8/25/2005	0.55			21.79			22.4		
DOE-33	8/25/2005	0.65			20.34			22.4		
DOE-34	8/25/2005	0.50	0.77	4.45	26.88	21.1	0.97	22.4	22.4	5.24
DOE-35	12/13/2005	1.25			23.43			21.9		
DOE-36	12/13/2005	1.45			11.09			21.9		
DOE-37	12/13/2005	1.40			11.39			21.9		
DOE-38	12/13/2005	1.95			17.78			21.9		
DOE-39	12/13/2005	2.35	1.68		9.66	14.7		21.9	21.9	
DOE-40	12/13/2005	1.60			12.29			21.2		
DOE-41	12/13/2005	1.85			18.60			21.2		
DOE-42	12/13/2005	1.70			20.61			21.2		
DOE-43	12/13/2005	1.60			20.52			21.2		
DOE-44	12/13/2005	1.65	1.68	0.00	18.68	18.1	15.0*	21.2	21.2	2.30
DOE 45	4/21/2006	1.65			15.65			19.7		
DOE 46	4/21/2006	2.70			16.32			19.7		
DOE 47	4/21/2006	3.00			14.80			19.7		
DOE 48	4/21/2006	2.15			14.62			19.7		
DOE 49	4/21/2006	1.95	2.29		14.52	15.2		19.7	19.7	
DOE 50	4/21/2006	1.60			17.29			19.6		

Sample	Date	Wet Weight	Average Wet Weight	Wet Weight Relative Std Deviation	Dry Matter	Average Dry Matter	Dry Weight Relative Std Deviation	Crude Protein	Average Crude Protein	Crude Protein Relative Std Deviation
		lbs	lbs	%	%	%	%	%	%	%
DOE 51	4/21/2006	2.50			17.86			19.6		
DOE 52	4/21/2006	2.05			17.19			19.6		
DOE 53	4/21/2006	2.10			16.72			19.6		
DOE 54	4/21/2006	2.15	2.08	6.80	16.80	17.2	8.68	19.6	19.6	0.36
DOE 55	5/25/2006	0.92			14.61			25.7		
DOE 56	5/25/2006	1.47			15.97			25.7		
DOE 57	5/25/2006	1.21			15.14			25.7		
DOE 58	5/25/2006	0.92			15.64			25.7		
DOE 59	5/25/2006	1.47	1.20		12.00	14.7		25.7	25.7	
DOE 60	5/25/2006	1.61			13.72			23.8		
DOE 61	5/25/2006	1.67			14.99			23.8		
DOE 62	5/25/2006	1.30			15.80			23.8		
DOE 63	5/25/2006	1.47			14.27			23.8		
DOE 64	5/25/2006	1.03	1.42	11.6*	16.52	15.1	1.84	23.8	23.8	5.43
DOE 65	7/5/2006	1.25			20.18			17.3		
DOE 66	7/5/2006	17.3			25.20			17.3		
DOE 67	7/5/2006	20.7			24.21			17.3		
DOE 68	7/5/2006	25.6			23.67			17.3		
DOE 69	7/5/2006	29.5	18.84		20.98	22.8		17.3	17.3	
DOE 70	7/5/2006	24.4			23.58			18.7		
DOE 71	7/5/2006	21.8			26.60			18.7		
DOE 72	7/5/2006	10.9			33.50			18.7		
DOE 73	7/5/2006	17.2			27.55			18.7		
DOE 74	7/5/2006	16.1	18.04	3.07	27.85	27.8	13.9*	18.7	18.7	5.50
DOE 75	8/15/2006	1.17			17.48			21.6		
DOE 76	8/15/2006	0.90			20.84			21.6		
DOE 77	8/15/2006	0.70			22.20			21.6		
DOE 78	8/15/2006	0.81			21.03			21.6		
DOE 79	8/15/2006	0.66	0.85		25.13	21.3		21.6	21.6	
DOE 80	8/15/2006	1.25			19.30			22.6		
DOE 81	8/15/2006	0.97			23.09			22.6		
DOE 82	8/15/2006	1.08			20.25			22.6		
DOE 83	8/15/2006	1.21			18.54			22.6		
DOE 84	8/15/2006	0.92	1.09	17.4*	20.05	20.2	3.71	22.6	22.6	3.20
DOE 85	9/27/2006	1.31			14.75			19.5		
DOE 86	9/27/2006	0.91			20.70			19.5		
DOE 87	9/27/2006	1.35			18.02			19.5		

		Wet Weight	Average Wet Weight	Wet Weight Relative Std Deviation	Dry Matter	Average Dry Matter	Dry Weight Relative Std Deviation	Crude Protein	Average Crude Protein	Crude Protein Relative Std Deviation
Sample	Date	lbs	lbs	%	%	%	%	%	%	%
DOE 88	9/27/2006	1.06			17.95			19.5		
DOE 89	9/27/2006	0.98	1.12		15.93	17.5		19.5	19.5	
DOE 90	9/27/2006	1.41			16.24			21.4		
DOE 91	9/27/2006	1.01			17.93			21.4		
DOE 92	9/27/2006	0.91			19.88			21.4		
DOE 93	9/27/2006	1.26			14.20			21.4		
DOE 94	9/27/2006	0.89	1.10	1.63	17.57	17.2	1.25	21.4	21.4	6.57
DOE 95	5/6/2007	2.65			14.78			18.2		
DOE 96	5/6/2007	3.30			15.92			18.2		
DOE 97	5/6/2007	4.15			13.26			18.2		
DOE 98	5/6/2007	2.90			15.03			18.2		
DOE 99	5/6/2007	2.85	3.17		14.80	14.8		18.2	18.2	
DOE 100	5/6/2007	4.55			15.24			15.9		
DOE 101	5/6/2007	3.70			17.31			15.9		
DOE 102	5/6/2007	3.10			18.12			15.9		
DOE 103	5/6/2007	2.75			17.52			15.9		
DOE 104	5/6/2007	3.30	3.48	6.59	14.16	16.5	7.74	15.9	15.9	9.54
DOE 105	6/14/2007	1.75			15.19			21.1		
DOE 106	6/14/2007	1.25			23.81			21.1		
DOE 107	6/14/2007	1.05			19.77			21.1		
DOE 108	6/14/2007	1.65			18.20			21.1		
DOE 109	6/14/2007	1.60	1.46		17.11	18.8		21.1	21.1	
DOE 110	6/14/2007	1.50			19.45			19.5		
DOE 111	6/14/2007	0.80			20.34			19.5		
DOE 112	6/14/2007	0.70			20.11			19.5		
DOE 113	6/14/2007	1.90			16.51			19.5		
DOE 114	6/14/2007	1.60	1.30	8.20	17.99	18.9	0.25	19.5	19.5	5.57
DOE 115	7/30/2007	1.20			22.80			19.4		
DOE 116	7/30/2007	1.40			19.52			19.4		
DOE 117	7/30/2007	1.05			20.14			19.4		
DOE 118	7/30/2007	1.30						19.4		
DOE 119	7/30/2007	0.95	1.18		19.76	20.6		19.4	19.4	
DOE 120	7/30/2007	1.55			17.12			19.7		
DOE 121	7/30/2007	1.60			19.44			19.7		
DOE 122	7/30/2007	0.90			22.95			19.7		
DOE 123	7/30/2007	1.15			21.32			19.7		
DOE 124	7/30/2007	1.00	1.24	3.51	22.22	20.6	0.20	19.7	19.7	1.09

		Wet Weight	Average Wet Weight	Wet Weight Relative Std Deviation	Dry Matter	Average Dry Matter	Dry Weight Relative Std Deviation	Crude Protein	Average Crude Protein	Crude Protein Relative Std Deviation
Sample	Date	lbs	lbs	%	%	%	%	%	%	%
DOE 125	8/28/2007	0.95			16.27			21.7		
DOE 126	8/28/2007	0.65			22.28			21.7		
DOE 127	8/28/2007	0.95			22.22			21.7		
DOE 128	8/28/2007	0.85			19.72			21.7		
DOE 129	8/28/2007	0.70	0.82		20.38	20.2		21.7	21.7	
DOE 130	8/28/2007	1.60			13.85			23.7		
DOE 131	8/28/2007	0.60			20.16			23.7		
DOE 132	8/28/2007	0.80			21.22			23.7		
DOE 133	8/28/2007	0.85			19.68			23.7		
DOE 134	8/28/2007	0.30	0.83	0.86	23.26	19.6	1.93	23.7	23.7	6.23
DOE 135	10/10/2007	1.30			13.56			25.3		
DOE 136	10/10/2007	0.90			16.56			25.3		
DOE 137	10/10/2007	1.75			16.66			25.3		
DOE 138	10/10/2007	1.40			11.47			25.3		
DOE 139	10/10/2007	1.00	1.27		12.67	14.2		25.3	25.3	
DOE 140	10/10/2007	1.20			10.59			26.2		
DOE 141	10/10/2007	1.10			15.27			26.2		
DOE 142	10/10/2007	0.70			17.07			26.2		
DOE 143	10/10/2007	1.15			13.72			26.2		
DOE 144	10/10/2007	0.60	0.95	20.4*	13.58	14.0	0.69	26.2	26.2	2.47
DOE 145	5/9/2008	1.90			18.41			17.5		
DOE 146	5/9/2008	2.10			17.87			17.5		
DOE 147	5/9/2008	1.70			19.26			17.5		
DOE 148	5/9/2008	2.05			17.05			17.5		
DOE 149	5/9/2008	2.25	2.00		14.02	17.3		17.5	17.5	
DOE 150	5/9/2008	2.35			17.16			18.4		
DOE 151	5/9/2008	2.05			17.62			18.4		
DOE 152	5/9/2008	2.25			19.87			18.4		
DOE 153	5/9/2008	1.95			16.82			18.4		
DOE 154	5/9/2008	2.25	2.17	5.77	18.99	18.1	3.07	18.4	18.4	3.55
DOE 155	6/16/2008	1.60			14.91			21.3		
DOE 156	6/16/2008	1.00			20.21			21.3		
DOE 157	6/16/2008	1.15			17.83			21.3		
DOE 158	6/16/2008	1.25			16.66			21.3		
DOE 159	6/16/2008	1.15	1.23		17.15	17.4		21.3	21.3	
DOE 160	6/16/2008	1.40			16.32			22.2		
DOE 161	6/16/2008	1.75			22.96			22.2		

		Wet Weight	Average Wet Weight	Wet Weight Relative Std Deviation	Dry Matter	Average Dry Matter	Dry Weight Relative Std Deviation	Crude Protein	Average Crude Protein	Crude Protein Relative Std Deviation
Sample	Date	lbs	lbs	%	%	%	%	%	%	%
DOE 162	6/16/2008	0.60			19.36			22.2		
DOE 163	6/16/2008	1.10			17.94			22.2		
DOE 164	6/16/2008	1.10	1.19	2.34	15.14	18.3	3.93	22.2	22.2	2.93
DOE 165	7/21/2008	1.10			13.99			21.7		
DOE 166	7/21/2008	0.70			20.94			21.7		
DOE 167	7/21/2008	1.15			20.73			21.7		
DOE 168	7/21/2008	1.05			17.40			21.7		
DOE 169	7/21/2008	1.10	1.02		18.44	18.3		21.7	21.7	
DOE 170	7/21/2008	1.50			14.31			19.3		
DOE 171	7/21/2008	0.85			21.37			19.3		
DOE 172	7/21/2008	1.15			22.01			19.3		
DOE 173	7/21/2008	0.95			19.06			19.3		
DOE 174	7/21/2008	0.80	1.05	2.05	22.58	19.9	5.79	19.3	19.3	8.28
DOE 175	9/2/2008	1.00			10.43			24.4		
DOE 176	9/2/2008	1.60			12.55			24.4		
DOE 177	9/2/2008	1.75			10.71			24.4		
DOE 178	9/2/2008	1.25			10.92			24.4		
DOE 179	9/2/2008	1.80	1.48		13.55	11.6		24.4	24.4	
DOE 180	9/2/2008	1.55			11.76			23.5		
DOE 181	9/2/2008	1.25			10.52			23.5		
DOE 182	9/2/2008	1.15			13.67			23.5		
DOE 183	9/2/2008	0.95			10.72			23.5		
DOE 184	9/2/2008	1.60	1.30	9.16	9.41	11.2	2.59	23.5	23.5	2.66
DOE 185	10/21/2008	9.20			16.83			23.7		
DOE 186	10/21/2008	19.4			18.01			23.7		
DOE 187	10/21/2008	11.5			23.14			23.7		
DOE 188	10/21/2008	11.8			17.52			23.7		
DOE 189	10/21/2008	16.2	13.59		19.53	19.0		23.7	23.7	
DOE 190	10/21/2008	14.2			16.00			25.8		
DOE 191	10/21/2008	14.3			15.03			25.8		
DOE 192	10/21/2008	19.4			19.51			25.8		
DOE 193	10/21/2008	9.80			17.89			25.8		
DOE 194	10/21/2008	14.6	14.42	4.19	17.51	17.2	7.11	25.8	25.8	6.00

* Relative standard deviations that exceeded 10%.

(MyDoc's/Data/Nooksack 2/Report/Final Report/Grasss.xlsx—QA table report tab)

Table K.3. Relative standard deviations for grass wet weight, dry weight, and crude protein.

	Wet Weight Relative Standard Deviation	Dry Weight Relative Standard Deviation	Crude Protein Relative Standard Deviation	N
	%	%	%	Number
Minimum	0.0	0.20	0.36	18
Maximum	20.4	15.0	9.54	18
Mean	6.51	4.55	4.51	18

(My Doc's/Data/Nooksack 2/Report/Final report 2010/Grass.xlsx—Rel Std Dev tab)

Table K.4. Results of soil split samples.

		Soil Nitrate	Gravimetric Soil Moisture
Date	Sample ID	ppm	% of dry weight
11/19/2004	DOE S17	17	--
11/19/2004	Split	16	--
Relative Standard Deviation (%)		4.3	--
5/27/2005	DOE S30	27	25.0
5/27/2005	DOE S29	32	24.7
Relative Standard Deviation (%)		12	0.85
8/11/2005	DOE S39	19	17.1
8/11/2005	DOE S45	17	16.6
Relative Standard Deviation (%)		7.9	2.1
9/7/2005	DOE S48	25	20.0
9/7/2005	DOE S56	31	19.6
Relative Standard Deviation (%)		15	1.4
10/4/2005	DOE S57	18	28.7
10/4/2005	DOE S59	14	28.7
Relative Standard Deviation (%)		18	0.0
11/1/2005	DOE S66	14	42.8
11/1/2005	DOE S68	14	42.9
Relative Standard Deviation (%)		0.0	0.13
11/29/2005	DOE S77	15	40.9
11/29/2005	DOE S79	13	40.9
Relative Standard Deviation (%)		10	0.0
3/30/2006	DOE S86	11	36.4
3/30/2006	DOE S88	15	32.5
Relative Standard Deviation (%)		22	7.9
7/24/2006	DOE S95	38	15.4
7/24/2006	DOE S97	35	14.6
Relative Standard Deviation (%)		5.8	3.8
8/22/2006	DOE S102	23	13.9
8/22/2006	DOE S104	21	14.6
Relative Standard Deviation (%)		6.4	3.6
7/23/2008	DOE S180	20.9	26.3
7/23/2008	DOE S182	17.5	26.0
Relative Standard Deviation (%)		12	0.85
8/29/2008	DOE S189	26.3	37.2
8/29/2008	DOE S191	21.8	37.2
Relative Standard Deviation (%)		13	0.0
9/26/2008	DOE S198	38.3	32.9
9/26/2008	DOE S200	44.3	32.7
Relative Standard Deviation (%)		10	0.57
10/31/2008	DOE S209	27.8	37.0
10/31/2008	DOE S211	32.2	36.6
Relative Standard Deviation (%)		10	0.81

(...Report/Final Report 2010/Soil nitrate/Soil nitrate data-_3_30_10.xlsx (Splits tab).

Table K.5. Soil nitrate duplicate results, means and relative standard deviations.

Date	Sample ID	Soil Nitrate (mg/kg)	Average Soil Nitrate (mg/kg)	Standard Deviation of Soil Nitrate	Relative Standard Deviation %
8/25/2004	DOE S1	54	51.5	3.54	6.87
8/25/2004	DOE S2	49			
9/9/2004	DOE S3	49	43.0	8.49	19.7
9/9/2004	DOE S4	37			
9/17/2004	DOE S5	27	28.5	2.12	7.44
9/17/2004	DOE S6	30			
10/1/2004	DOE S7	14	19.0	7.07	37.2*
10/1/2004	DOE S8	24			
10/22/2004	DOE S11	24	26.5	3.54	13.3
10/22/2004	DOE S12	29			
11/12/2004	DOE S15	23	22.5	0.71	3.14
11/12/2004	DOE S16	22			
11/19/2004	DOE S17	17	18.5	2.12	11.5
11/19/2004	DOE S18	20			
12/3/2004	DOE S19	16	16.0	0.00	0.00
12/3/2004	DOE S20	16			
2/22/2005	DOE S22	16	16.5	0.71	4.29
2/22/2005	DOE S23	17			
3/25/2005	DOE S24	15	14.5	0.71	4.88
3/25/2005	DOE S25	14			
4/28/2005	DOE S26	15	16.0	1.41	8.84
4/28/2005	DOE S27	17			
5/27/2005	DOE S28	31	31.5	0.71	2.24
5/27/2005	DOE S29	32			
6/29/2005	DOE S31	13	17.0	5.66	33.3*
6/29/2005	DOE S32	21			
7/28/2005	DOE S35	5	5.5	0.71	12.86
7/28/2005	DOE S36	6			
8/5/2005	DOE S37	5	5.0	0.00	0.00
8/5/2005	DOE S38	5			
8/11/2005	DOE S39	19	19.0	0.00	0.00
8/11/2005	DOE S40	19			
8/17/2005	DOE S41	24	29.5	7.78	26.4*
8/17/2005	DOE S42	35			
8/24/2005	DOE S43	18	21.0	4.24	20.2*
8/24/2005	DOE S44	24			
8/31/2005	DOE S46	29	28.0	1.41	5.05

Date	Sample ID	Soil Nitrate (mg/kg)	Average Soil Nitrate (mg/kg)	Standard Deviation of Soil Nitrate	Relative Standard Deviation %
8/31/2005	DOE S47	27			
9/7/2005	DOE S48	25	30.0	7.07	23.6*
9/7/2005	DOE S49	35			
9/13/2005	DOE S50	22	26.5	6.36	24.0*
9/13/2005	DOE S51	31			
9/21/2005	DOE S52	19	21.0	2.83	13.5
9/21/2005	DOE S53	23			
9/27/2005	DOE S54	14	16.5	3.54	21.4*
9/27/2005	DOE S55	19			
10/4/2005	DOE S57	18	15.5	3.54	22.8*
10/4/2005	DOE S58	13			
10/11/2005	DOE S60	16	16.0	0.00	0.00
10/11/2005	DOE S61	16			
10/18/2005	DOE S62	14	11.5	3.54	30.7*
10/18/2005	DOE S63	9			
10/25/2005	DOE S64	10	22.0	16.97	77.1*
10/25/2005	DOE S65	34			
11/1/2005	DOE S66	14	11.5	3.54	30.7*
11/1/2005	DOE S67	9			
11/10/2005	DOE S71	9	5.5	4.95	90.0*
11/10/2005	DOE S72	2			
11/15/2005	DOE S73	9	10.0	1.41	14.1
11/15/2005	DOE S74	11			
11/21/2005	DOE S75	15	16.5	2.12	12.9
11/21/2005	DOE S76	18			
11/29/2005	DOE S77	15	14.5	0.71	4.88
11/29/2005	DOE S78	14			
12/16/2005	DOE S80	17	17.0	0.00	0.0
12/16/2005	DOE S81	17			
1/19/2006	DOE S82	11	10.0	1.41	14.1
1/19/2006	DOE S83	9			
2/22/2006	DOE S84	14	13.0	1.41	10.9
2/22/2006	DOE S85	12			
3/30/2006	DOE S86	11	12.5	2.12	17.0
3/30/2006	DOE S87	14			
4/27/2006	DOE S91	14	13.5	0.71	5.24
4/27/2006	DOE S92	13			
5/25/2006	DOE S89	27.6	32.8	7.28	22.2*

Date	Sample ID	Soil Nitrate (mg/kg)	Average Soil Nitrate (mg/kg)	Standard Deviation of Soil Nitrate	Relative Standard Deviation %
5/25/2006	DOE S90	37.9			
6/27/2006	DOE S93	21	22.0	1.41	6.43
6/27/2006	DOE S94	23			
7/24/2006	DOE S95	38	40.0	2.83	7.07
7/24/2006	DOE S96	42			
8/3/2006	DOE S98	31	30.5	0.71	2.32
8/3/2006	DOE S99	30			
8/11/2006	DOE S100	29	26.0	4.24	16.3
8/11/2006	DOE S101	23			
8/15/2006	C5420	20.6	19.8	1.20	6.09
8/15/2006	C5421	18.9			
8/22/2006	DOE S102	23	20.5	3.54	17.2
8/22/2006	DOE S103	18			
8/30/2006	DOE S105	24	21.0	4.24	20.2*
8/30/2006	DOE S106	18			
9/6/2006	DOE S107	21	22.5	2.12	9.43
9/6/2006	DOE S108	24			
9/13/2006	DOE S109	16	17.0	1.41	8.32
9/13/2006	DOE S110	18			
9/20/2006	C5542	14	15.5	2.12	13.7
9/20/2006	C5543	17			
9/27/2006	C5544	21	23.0	2.83	12.3
9/27/2006	C5545	25			
10/4/2006	C5546	19	17.0	2.83	16.6
10/4/2006	C5547	15			
10/12/2006	C5548	18	18.0	0.00	0.0
10/12/2006	C5549	18			
10/18/2006	C5656	22	25.0	4.24	17.0
10/18/2006	C5657	28			
10/26/2006	C5658	29	29.0	0.00	0.0
10/26/2006	C5659	29			
11/1/2006	C5660	27	30.5	4.95	16.2
11/1/2006	C5661	34			
11/8/2006	C5590	60	60.0	0.00	0.0
11/8/2006	C5591	60			
11/15/2006	C5662	18	15.5	3.54	22.8*
11/15/2006	C5663	13			
11/21/2006	C5602	14	13.5	0.71	5.24

Date	Sample ID	Soil Nitrate (mg/kg)	Average Soil Nitrate (mg/kg)	Standard Deviation of Soil Nitrate	Relative Standard Deviation %
11/21/2006	C5603	13			
12/20/2006	C5604	13	14.0	1.41	10.1
12/20/2006	C5605	15			
1/26/2007	DOE S111	12.7	11.9	1.13	9.51
1/26/2007	DOE S112	11.1			
2/23/2007	DOE S113	10.2	10.0	0.35	3.55
	DOE S114	9.7			
3/23/2007	DOE S115	6.1	6.1	0.07	1.17
	DOE S116	6.0			
4/25/2007	DOE S117	9.2	12.4	2.96	23.8*
	DOE S118	13.1			
	DOE S119	15.0			
5/16/2007	DOE S120	16.7	18.4	2.33	12.7
	DOE S121	20.0			
6/26/2007	DOE S122	24.4	23.5	1.34	5.73
	DOE S123	22.5			
7/24/2007	DOE S124	21.7	22.6	1.27	5.63
	DOE S125	23.5			
8/7/2007	DOE S126	18.6	17.0	1.36	7.97
	DOE S127	16.3			
	DOE S128	16.2			
8/15/2007	DOE S129	23.3	20.7	3.68	17.8
	DOE S130	18.1			
8/21/2007	DOE S131	20.0	19.9	0.14	0.71
	DOE S132	19.8			
8/28/2007	DOE S133	17.4	18.3	1.27	6.96
	DOE S134	19.2			
9/5/2007	DOE S135	14.3	15.4	1.57	10.2
	DOE S136	17.2			
	DOE S137	14.7			
9/11/2007	DOE S138	27.0	25.3	2.47	9.80
	DOE S139	23.5			
9/18/2007	DOE S140	16.6	15.4	1.77	11.5
	DOE S141	14.1			
9/25/2007	DOE S142	17.2	14.7	3.61	24.6*
	DOE S143	12.1			
10/2/2007	DOE S144	10.9	13.0	4.26	32.8*
	DOE S145	17.9			

Date	Sample ID	Soil Nitrate (mg/kg)	Average Soil Nitrate (mg/kg)	Standard Deviation of Soil Nitrate	Relative Standard Deviation %
	DOE S146	10.2			
10/9/2007	DOE S147 DOE S148	16.7 17.1	16.9	0.28	1.67
10/16/2007	DOE S149 DOE S150	18.0 19.5	18.8	1.06	5.66
10/23/2007	DOE S151 DOE S152	14.1 15.2	14.7	0.78	5.31
10/30/2007	DOE S153 DOE S154 DOE S155	10.8 12.8 11.2	11.6	1.06	9.12
11/6/2007	DOE S156 DOE S157	11.3 11.7	11.5	0.28	2.46
11/13/2007	DOE S158 DOE S159	10.6 9.8	10.2	0.57	5.55
11/20/2007	DOE S160 DOE S161	12.6 9.3	11.0	2.33	21.3*
11/27/2007	DOE S162 DOE S163 DOE S164	12.4 11.4 12.2	12.0	0.53	4.41
12/21/2007	DOE S165 DOE S166	19 17	18.0	1.41	7.86
1/22/2008	DOE S167 DOE S168	22 19	20.5	2.12	10.3
2/22/2008	DOE S169 DOE S170	10.1 11.1	10.6	0.71	6.67
3/18/2008	DOE S171 DOE S172 DOE S173	15.5 12.7 14.1	14.1	1.40	9.93
4/22/2008	DOE S174 DOE S175	16.7 18.1	17.4	0.99	5.69
5/27/2008	DOE S176 DOE S177	28.8 29.7	29.3	0.64	2.18
6/25/2008	DOE S178 DOE S179	33.5 35.1	34.3	1.13	3.30
7/23/2008	DOE S180 DOE S181 DOE S182	19.1 15.3 14.7	14.1	1.40	9.93
8/6/2008	DOE S183	35.4	29.7	8.06	27.1*

Date	Sample ID	Soil Nitrate (mg/kg)	Average Soil Nitrate (mg/kg)	Standard Deviation of Soil Nitrate	Relative Standard Deviation %
	DOE S184	24.0			
8/15/2008	DOE S185	25.8	25.4	0.57	2.23
	DOE S186	25.0			
8/22/2008	DOE S187	19.2	22.3	4.38	19.7
	DOE S188	25.4			
8/29/2008	DOE S189	26.3	21.3	5.27	24.7*
	DOE S190	15.8			
	DOE S191	21.8			
9/5/2008	DOE S192	22.1	20.9	1.70	8.12
	DOE S193	19.7			
9/12/2008	DOE S194	27.0	29.5	3.54	12.0
	DOE S195	32.0			
9/19/2008	DOE S196	33.9	35.9	2.83	7.88
	DOE S197	37.9			
9/26/2008	DOE S198	38.3	42.2	3.41	8.07
	DOE S199	44.1			
	DOE S200	44.3			
10/3/2008	DOE S201	24.8	26.5	2.40	9.07
	DOE S202	28.2			
10/10/2008	DOE S203	17.6	21.6	5.66	26.2*
	DOE S204	25.6			
10/17/2008	DOE S205	21.2	26.9	7.99	29.8*
	DOE S206	32.5			
10/24/2008	DOE S207	26.2	30.8	6.43	20.9*
	DOE S208	35.3			
10/31/2008	DOE S209	27.8	30.7	2.48	8.10
	DOE S210	32.0			
	DOE S211	32.2			
11/7/2008	DOE S212	9.2	9.6	0.49	5.18
	DOE S213	9.9			
11/14/2008	DOE S214	10.6	10.9	0.42	3.89
	DOE S215	11.2			
11/21/2008	DOE S216	13.3	11.7	2.26	19.3
	DOE S217	10.1			
11/28/2008	DOE S218	12.8	13.3	1.67	12.5
	DOE S219	15.2			
	DOE S220	12.0			

(...Report/Final Report 2010/Soil nitrate/Soil nitrate data-_3_30_10.xlsx (NO3 Rel STD tab)

* Relative standard deviation exceeds acceptable limit of 20%.

Table K.6. Relative standard deviation of replicate groundwater quality results in mg/L except conductivity (umhos/cm), temperature (⁰C), and pH (Standard Units).

Well ID	Date	Temp- erature	pH	Dissolved Oxygen	Field Conductivity	Ammonia- N	Nitrate+ Nitrite-N	Total Persulfate N	Ortho Phosphorus	Total Phosphorus	Chloride	TDS	Dissolved Organic Carbon
September 20-21, 2004													
AKG-724	9/21/2004	13.7	4.69	8.60	408	<0.010	19.7	19.2	0.0058	0.0060	18.6	270	1.7
AKG-724	9/21/2004	13.5	4.79	6.90	406	<0.010	20.3	19.6	0.0061	0.0044	19.0	268	1.7
Relative Standard Deviation		1.0	1.5	15.5	0.3	--	2.1	1.5	3.6	21.8	1.5	0.5	0.0
October 18-19, 2004													
AKG-725	10/19/2004	12.1	NA	5.60	444	0.017	26.8	33.2	0.0072	0.0028	19.9	315	1.8
AKG-725	10/19/2004	12.1	NA	6.00	448	0.018	24.3	30.9	0.0075	0.0034	20.0	316	1.9
Relative Standard Deviation		0.0		4.9	0.6	4.0	6.9	5.1	2.9	13.7	0.4	0.2	3.8
November 22-23, 2004													
AKG-725	11/23/2004	11.8	5.72	8.09	486	<0.010	30.8	32.4	0.0054	0.0037	22.6	323	1.8
AKG-725	11/23/2004	11.7	5.71	7.97	474	<0.010	29.4	33.5	0.0056	0.0040	21.6	353	1.4
Relative Standard Deviation		0.6	0.1	1.1	1.8	--	3.3	2.4	2.6	5.5	3.2	6.3	17.7
December 28-29, 2004													
AKG-722	12/28/2004	9.6	5.51	8.30	599	<0.010	45.3	43.7	0.0043	0.0032	30.6	381	4.9
AKG-722	12/28/2004	9.7	5.50	7.40	580	<0.010	43.4	42.1	0.0044	0.0034	29.0	383	4.5
Relative Standard Deviation		0.7	0.1	8.1	2.3	--	3.0	2.6	1.6	4.3	3.8	0.4	6.0
February 1, 2005													
AKG-725	2/1/2005	8.0	5.68	9.60	435	<0.010	34.0	29.9	0.0090	0.0090	16.4	315	1.6
AKG-725	2/1/2005	8.0	5.65	9.70	442	<0.010	31.3	27.3	0.0086	0.0080	16.8	303	1.6
Relative Standard Deviation		0.0	0.4	0.7	1.1	--	5.8	6.4	3.2	8.3	1.7	2.7	0.0
March 2-3, 2005													
AKG-723	3/2/2005	8.6	5.09	3.41	556	<0.010	39.5	39.1	0.0051	0.0037	22.2	358	2.3
AKG-723	3/2/2005	8.7	5.06	3.75	566	<0.010	40.6	39.1	0.0051	0.0036	22.5	394	2.4
Relative Standard Deviation		0.8	0.4	6.7	1.3	--	1.9	0.0	0.0	1.9	0.9	6.8	3.0
March 30-31, 2005													
AKG-727	3/30/2005	9.1	5.16	3.64	364	<0.010	19.2	22.7	0.0049	0.0043	14.9	254	2.2
AKG-727	3/30/2005	9.9	5.48	3.73	362	<0.010	18.4	23.8	0.0048	0.0036	14.7	264	2.1
Relative Standard Deviation		6.0	4.3	1.7	0.4	--	3.0	3.3	1.5	12.5	1.0	2.7	3.3
April 25-26, 2005													
AKG-722	4/25/2005	9.8	5.68	6.87	236	<0.010	11.2	11.0	NA	0.0048	7.14	166	6.8
AKG-722	4/25/2005	9.8	5.66	6.70	237	<0.010	10.8	11.2	NA	0.0039	7.15	170	6.7
Relative Standard Deviation		0.0	0.2	1.8	0.3	--	2.6	1.3	--	14.6	0.1	1.7	1.0

Well ID	Date	Temperature	pH	Dissolved Oxygen	Field Conductivity	Ammonia-N	Nitrate+Nitrite-N	Total Persulfate N	Ortho Phosphorus	Total Phosphorus	Chloride	TDS	Dissolved Organic Carbon
May 25-26, 2005													
AKG-725	5/26/2005	10.6	5.79	6.73	475	<0.010	29.3	34.7	NA	0.0473	24.6	362	1.7
AKG-725	5/26/2005	10.7	5.73	6.75	478	<0.010	29.4	32.6	NA	0.0072	24.5	330	1.8 J
Relative Standard Deviation		0.7	0.7	0.2	0.4	--	0.2	4.4	--	104.1	0.3	6.5	4.0 J
July 6-7, 2005													
AKG-722	7/6/2005	12.0	5.43	2.64	278	<0.010	11.9	10.9	NA	0.0038	11.0	200	4.9
AKG-722	7/6/2005	11.6	5.49	2.39	280	<0.010	11.8	10.8	NA	0.0038	11.3	186	4.8
Relative Standard Deviation		2.4	0.8	7.0	0.5	--	0.6	0.7	--	--	1.9	5.1	1.5
August 16-17, 2005													
AKG-723	8/16/2005	12.2	5.22	2.83	441	<0.010	28.5	29.6	NA	0.0032	20.0	336	1.3
AKG-723	8/16/2005	12.6	5.23	2.68	444	<0.010	32.2	29.0	NA	0.0033	20.1	322	1.5
Relative Standard Deviation		2.3	0.1	3.8	0.5	--	8.6	1.4	--	2.2	0.4	3.0	10.1
September 21-22, 2005													
AKG-727	9/21/2005	13.7	5.19	2.53	383	<0.010	13.2	14.5	NA	0.0037	17.6	254	2.2
AKG-727	9/21/2005	13.2	5.20	2.60	385	<0.010	13.0	14.5	NA	0.0048	17.6	241	2.3
Relative Standard Deviation		2.6	0.1	1.9	0.4	--	1.1	0.0	--	18.3	0.0	3.7	3.1
October 19-20, 2005													
AKG-724	10/19/2005	12.6	4.94	6.26	337	<0.010	13.2	12.7	NA	0.0021	19.1	258	2.0
AKG-724	10/19/2005	12.5	4.90	5.96	325	<0.010	12.9	12.8	NA	0.0190	19.2	256	1.9
Relative Standard Deviation		0.6	0.6	3.5	2.6	--	1.6	0.6	--	113.3	0.4	0.6	3.6
November 16-17, 2005													
AKG-722	11/16/2005	11.4	5.56	0.85	352	<0.010	9.2	9.09	NA	0.0037	15.5	227	2.9
AKG-722	11/16/2005	11.0	5.52	0.66	347	<0.010	9.77	8.34	NA	0.0033	15.4	226	2.9
Relative Standard Deviation		2.5	0.5	17.8	1.0	--	4.2	6.1	--	8.1	0.5	0.3	0.0
December 14-15, 2005													
AKG-724	12/14/2005	10.6	4.67	1.90	426	<0.010	19.0	19.5	NA	0.0023	17.8	287	1.8
AKG-724	12/14/2005	10.0	4.71	1.32	423	<0.010	19.1	18.9	NA	0.0022	17.7	282	1.7
Relative Standard Deviation		4.1	0.6	25.5	0.5	--	0.4	2.2	--	3.1	0.4	1.2	4.0
January 10-11, 2006													
AKG-723	1/10/2006	8.7	5.53	3.74	374	<0.010	22.0	18.9	NA	0.0077	13.0	260	4.3
AKG-723	1/11/2006	8.5	5.50	4.45	338	<0.010	18.5	18.2	NA	0.0071	12.9	267	4.2
Relative Standard Deviation		1.6	0.4	12.3	7.2	--	12.2	2.7	--	5.7	0.5	1.9	1.7

Well ID	Date	Temperature	pH	Dissolved Oxygen	Field Conductivity	Ammonia-N	Nitrate+Nitrite-N	Total Persulfate N	Ortho Phosphorus	Total Phosphorus	Chloride	TDS	Dissolved Organic Carbon
February 7-8, 2006													
AKG-725	2/8/2006	8.0	5.81	8.40	260	<0.010	9.93	10.0	NA	0.010	8.13	141	2.2
AKG-725	2/8/2006	8.1	5.80	7.43	261	<0.010	10.4	10.8	NA	0.011	8.12	177	2.2
Relative Standard Deviation		0.9	0.1	8.7	0.3	--	3.3	5.4	--	6.7	0.1	16.0	0.0
March 7-8, 2006													
AKG-725	3/8/2006	8.2	5.81	6.35	263	<0.010	10.4	12.6	NA	0.012	8.36	196	1.9
AKG-725	3/8/2006	8.4	5.70	6.47	286	<0.010	13.2	13.2	NA	0.012	9.28	204	1.6
Relative Standard Deviation		1.7	1.4	1.3	5.9	--	16.8	3.3	--	0.0	7.4	2.8	12.1
April 4-5, 2006													
AKG-722	4/4/2006	10.1	5.58	8.34	226	<0.010	9.94	11.0	NA	<0.0050	10.9	157	7.1
AKG-722	4/4/2006	9.8	5.54	8.40	248	<0.010	11.4	11.5	NA	<0.0050	10.9	177	5.9
Relative Standard Deviation		2.1	0.5	0.5	6.6	--	9.7	3.1	--	--	0.0	8.5	13.1
May 17-18, 2006													
AKG-724	5/17/2006	10.5	4.77	1.12	279	<0.010	8.52	9.9	NA	<0.0050	11.8	197	1.5
AKG-724	5/17/2006	10.4	4.80	1.01	273	<0.010	7.32	9.2	NA	<0.0050	12.0	196	1.5
Relative Standard Deviation		0.7	0.4	7.3	1.5	--	10.7	5.3	--	--	1.2	0.4	0.0
June 26-27, 2006													
AKG-724	6/26/2006	12.0	4.82	4.20	277	<0.010	9.04	10.8	NA	<0.0050	13.7	192	1.7
AKG-724	6/26/2006	12.4	4.87	4.81	276	<0.010	8.77	8.76	NA	<0.0050	13.9	185	1.7
Relative Standard Deviation		2.3	0.7	9.6	0.3	--	2.1	14.7	--	--	1.0	2.6	0.0
August 2-3, 2006													
AKG-722	8/2/2006	12.9	5.48	5.24	275	<0.010	7.44	8.90	NA	0.0033	12.4	197	3.4
AKG-722	8/2/2006	12.4	5.51	6.42	273	<0.010	8.46	9.06	NA	0.0033	12.6	193	3.1
Relative Standard Deviation		2.8	0.4	14.3	0.5	--	9.1	1.3	--	0.0	1.1	1.5	6.5
September 13-14, 2006													
AKG-722	9/13/2006	12.1	5.50	1.34	271	<0.010	5.80	5.94	NA	0.0040	12.3	190	3.0
AKG-722	9/13/2006	12.1	5.48	1.64	266	<0.010	6.60	6.51	NA	0.0038	12.4	188	3.5
Relative Standard Deviation		0.0	0.3	14.2	1.3	--	9.1	6.5	--	3.6	0.6	0.7	10.9
October 18-19, 2006													
AKG-725	10/18/2006	11.7	5.81	6.07	292	<0.010	10.0	8.20	NA	0.0106	9.20	204	3.9
AKG-725	10/18/2006	11.6	5.81	5.85	292	<0.010	9.54	8.18	NA	0.0108	9.26	204	3.8
Relative Standard Deviation		0.6	0.0	2.6	0.0	--	3.3	0.2	--	1.3	0.5	0.0	1.8

Well ID	Date	Temperature	pH	Dissolved Oxygen	Field Conductivity	Ammonia-N	Nitrate+Nitrite-N	Total Persulfate N	Ortho Phosphorus	Total Phosphorus	Chloride	TDS	Dissolved Organic Carbon
November 14-15, 2006													
AKG-722	11/14/2006	10.9	5.65	0.25	312	<0.010	1.82	1.54	NA	0.0050	13.1	201	3.6
AKG-722	11/14/2006	11.0	5.64	0.24	314	<0.010	2.31	2.23	NA	0.0044	13.2	200	4.7
Relative Standard Deviation		0.6	0.1	2.9	0.5	--	16.8	25.9	--	9.0	0.5	0.4	18.7
December 12-13, 2006													
AKG-724	12/12/2006	10.4	4.85	4.92	299	<0.010	9.66	8.81	NA	0.0030	17.2	199	1.7
AKG-724	12/12/2006	10.0	4.84	4.15	301	<0.010	9.70	9.60	NA	0.0024	11.1	202	2.3
Relative Standard Deviation		2.8	0.1	12.0	0.5	--	0.3	6.1	--	15.7	30.5	1.1	21.2
January 17-18, 2007													
AKG-724	1/17/2007	8.3	4.99	5.56	308	<0.010	13.9	14.3	NA	NA	16.2	215	2.5
AKG-724	1/17/2007	8.5	4.94	4.99	312	<0.010	14.3	15.0	NA	NA	16.2	214	2.2
Relative Standard Deviation		1.7	0.7	7.6	0.9	--	2.0	3.4	--	--	0.0	0.3	9.0
February 12-13, 2007													
AKG-723	2/12/2007	8.0	5.38	1.74	355	<0.010	19.6	20.4	NA	NA	11.1	203	3.2
AKG-723	2/12/2007	8.1	5.37	3.51	358	<0.010	19.9	19.7	NA	NA	14.9	251	2.8
Relative Standard Deviation		0.9	0.1	47.7	0.6	--	1.1	2.5	--	--	20.7	15.0	9.4
March 28-29, 2007													
AKG-727	3/28/2007	8.9	5.58	2.58	241	<0.010	6.12	6.69	NA	NA	6.80	166	2.4
AKG-727	3/28/2007	8.8	5.55	3.95	243	<0.010	5.68	6.65	NA	NA	6.88	166	2.3
Relative Standard Deviation		0.8	0.4	29.7	0.6	--	5.3	0.4	--	--	0.8	0.0	3.0
May 14-15, 2007													
AKG-724	5/14/2007	10.1	5.01	0.87	270	<0.010	11.9	11.9	NA	NA	10.6	179	1.7
AKG-724	5/14/2007	10.0	5.03	0.96	264	<0.010	11.1	9.71	NA	NA	10.8	174	1.7
Relative Standard Deviation		0.7	0.3	7.0	1.6	--	4.9	14.3	--	--	1.3	2.0	0.0
June 13-14, 2007													
AKG-727	6/13/2007	10.4	5.46	3.25	278	<0.010	7.63	7.89	NA	NA	7.91	193	2.3
AKG-727	6/13/2007	10.3	5.42	3.14	276	<0.010	7.65	7.84	NA	NA	7.99	190	2.3
Relative Standard Deviation		0.7	0.5	2.4	0.5	--	0.2	0.4	--	--	0.7	1.1	0.0
July 30-31, 2007													
AKG-725	7/30/2007	11.3	5.97	7.82	281	<0.010	10.7	11.4	NA	NA	9.88	201	2.0
AKG-725	7/30/2007	11.4	6.00	6.98	287	<0.010	10.9	11.2	NA	NA	9.94	201	1.5
Relative Standard Deviation		0.6	0.4	8.0	1.5	--	1.3	1.3	--	--	0.4	0.0	20.2

Well ID	Date	Temperature	pH	Dissolved Oxygen	Field Conductivity	Ammonia-N	Nitrate+Nitrite-N	Total Persulfate N	Ortho Phosphorus	Total Phosphorus	Chloride	TDS	Dissolved Organic Carbon
September 2-3, 2007													
AKG-723	9/2/2007	11.8	5.35	1.87	298	<0.010	15.6	12.6	NA	NA	9.41	209	1.9
AKG-723	9/2/2007	11.7	5.37	1.82	298	<0.010	12.7	12.6	NA	NA	9.47	214	2.0
Relative Standard Deviation		0.6	0.3	1.9	0.0	--	14.5	0.0	--	--	0.4	1.7	3.6
October 1-2, 2007													
AKG-723	10/1/2007	11.8	5.33	1.20	299	<0.010	12.7	12.2	NA	NA	8.93	216	1.8
AKG-723	10/1/2007	11.8	5.35	1.05	299	<0.010	12.2	12.2	NA	NA	8.75	207	1.8
Relative Standard Deviation		0.0	0.3	9.4	0.0	--	2.8	0.0	--	--	1.4	3.0	0.0
October 30-31, 2007													
AKG-725	10/30/2007	11.4	5.81	4.64	298	<0.010	9.54	9.76	NA	NA	9.08	206	1.7
AKG-725	10/30/2007	11.3	5.84	4.82	297	<0.010	9.66	10.5	NA	NA	9.04	200	1.5
Relative Standard Deviation		0.6	0.4	2.7	0.2	--	0.9	5.2	--	--	0.3	2.1	8.8
November 27-28, 2007													
AKG-725	11/28/2007	9.8	5.97	7.99	285	<0.010	10.4	10.0	NA	NA	7.93	191	1.7
AKG-725	11/28/2007	9.8	5.93	7.91	276	<0.010	11.5	10.2	NA	NA	7.96	192	1.6
Relative Standard Deviation		0.0	0.5	0.7	2.3	--	7.1	1.4	--	--	0.3	0.4	4.3
January 3-4, 2008													
AKG-724	1/3/2008	8.8	4.95	3.87	231	<0.010	6.68	6.69	NA	NA	7.87	153	1.9
AKG-724	1/3/2008	8.8	4.99	3.75	230	<0.010	6.16	6.17	NA	NA	7.81	156	2.0
Relative Standard Deviation		0.0	0.6	2.2	0.3	--	5.7	5.7	--	--	0.5	1.4	3.6
January 30-31, 2008													
AKG-721	1/30/2008	8.0	5.86	10.00	229	<0.010	8.01	9.08	NA	NA	5.79	153	1.7
AKG-721	1/30/2008	8.1	5.86	9.30	226	<0.010	8.03	9.34	NA	NA	7.59	149	1.6
Relative Standard Deviation		0.9	0.0	5.1	0.9	--	0.2	2.0	--	--	19.0	1.9	4.3
Feb 27-28, 2008													
AKG-725	2/28/2008	7.6	5.86	9.36	249	<0.010	12.1	12.5	NA	NA	6.04	179	1.7
AKG-725	2/28/2008	7.7	5.84	9.52	249	<0.010	12.2	12.2	NA	NA	6.07	178	1.7
Relative Standard Deviation		0.9	0.2	1.2	0.0	--	0.6	1.7	--	--	0.4	0.4	0.0
April 1-2, 2008													
AKG-722	4/1/2008	8.4	5.82	7.85	250	<0.010	9.98	10.7	NA	NA	4.56	169	9.4
AKG-722	4/1/2008	8.1	5.76	6.68	242	<0.010	8.78	9.78	NA	NA	4.72	164	8.4
Relative Standard Deviation		2.6	0.7	11.4	2.3	--	9.0	6.4	--	--	2.4	2.1	7.9

Well ID	Date	Temperature	pH	Dissolved Oxygen	Field Conductivity	Ammonia-N	Nitrate+Nitrite-N	Total Persulfate N	Ortho Phosphorus	Total Phosphorus	Chloride	TDS	Dissolved Organic Carbon
May 6-7, 2008													
AKG-725	5/7/2008	9.3	5.89	9.49	229	<0.010	7.53	6.92	NA	NA	4.85	178	1.6
AKG-725	5/7/2008	8.6	5.87	8.87	236	<0.010	7.56	7.53	NA	NA	5.60	180	1.6
Relative Standard Deviation		5.5	0.2	4.8	2.1	--	0.3	6.0	--	--	10.1	0.8	0.0
June 18-19, 2008													
AKG-722	6/18/2008	10.4	5.69	5.03	223	<0.010	8.10	8.92	NA	NA	4.40	163	7.6
AKG-722	6/18/2008	10.5	5.62	5.05	222	<0.010	8.19	8.35	NA	NA	4.42	164	6.7
Relative Standard Deviation		0.7	0.9	0.3	0.3	--	0.8	4.7	--	--	0.3	0.4	8.9
July 22-23, 2008													
AKG-723	7/22/2008	11.7	5.35	2.03	279	<0.010	8.53	8.32	NA	NA	6.73	185	2.1
AKG-723	7/22/2008	11.4	5.65	1.97	281	<0.010	8.13	8.37	NA	NA	6.67	193	2.0
Relative Standard Deviation		1.8	3.9	2.1	0.5	--	3.4	0.4	--	--	0.6	3.0	3.4
Sept. 8-9, 2008													
AKG-725	9/9/2008	11.5	5.84	5.40	243	<0.010	7.63	7.82	NA	NA	4.18	155	1.7
AKG-725	9/9/2008	11.6	5.82	5.60	242	<0.010	7.19	7.40	NA	NA	4.19	165	1.6
Relative Standard Deviation		0.6	0.2	2.6	0.3	--	4.2	3.9	--	--	0.2	4.4	4.3
October 7-8, 2008													
AKG-723	10/7/2008	11.9	5.34	2.89	266	<0.010	8.00	8.22	NA	NA	7.16	198	2.0
AKG-723	10/7/2008	11.8	5.30	1.55	267	<0.010	7.55	8.39	NA	NA	7.21	188	1.9
Relative Standard Deviation		0.6	0.5	42.7	0.3	--	4.1	1.4	--	--	0.5	3.7	3.6
November 12-13, 2008													
AKG-722	11/12/2008	11.3	5.66	0.45	221	<0.010	1.90	2.21	NA	NA	4.98	147	4.1
AKG-722	11/12/2008	11.2	5.62	0.65	220	<0.010	1.73	1.90	NA	NA	4.76	141	4.0
Relative Standard Deviation		0.6	0.5	25.7	0.3	--	6.6	10.7	--	--	3.2	2.9	1.7
December 9-10, 2008													
AKG-723	12/9/2008	10.0	5.44	1.88	274	<0.010	9.42	9.85	NA	NA	6.30	186	4.0
AKG-723	12/9/2008	10.4	5.41	2.10	274	<0.010	9.52	9.79	NA	NA	5.85	198	3.6
Relative Standard Deviation		2.8	0.4	7.8	0.0	--	0.7	0.4	--	--	5.2	4.4	7.4

(Nooksack2—older files\Report\Final report\ QA_01_02_13.xls /QA data tab)

Table K.7. Summary of relative standard deviation results for groundwater constituents. Units are in mg/L unless stated otherwise.

	Temp- erature (C°)	pH	Dissolved Oxygen	Conductivity (Field, umhos/cm)	Ammonium- N	Nitrate+ nitrite-N	Total Persulfate N	Ortho Phosphorus	Total Dissolved Phosphorus	Chloride	TDS	Dissolved Organic Carbon
Mean Rel Std Dev (%)	1.4	0.6	8.7	1.1	4.0	4.6	3.9	2.2	17	2.7	2.7	5.3
Number of samples (n)	47	46	47	47	1	47	47	7	22	47	47	47
Minimum Rel Std Dev (%)	0	0	0.21	0	4.0	0.18	0	0	0	0	0	0
Maximum Rel Std Dev (%)	6.0	4.3	48	7.2	4.0	17	26	3.6	113	30	16	21

(fromQA.xls/QA Stat Table tab)

Table K.8. Field blank results using blank water provided by MEL in mg/L.

Date	Ammonia-N	Nitrate+ Nitrite-N	Total Persulfate N	Chloride	TDS	Dissolved Organic Carbon
5/6/2008	<0.010	0.135	0.138	0.13	<10	<1.0
6/19/2008	<0.010	0.024	0.035			
7/23/2008	<0.010	<0.010	<0.025			
9/9/2008	<0.010	<0.010	<0.025			
10/8/2008	<0.010	<0.010	<0.025			<1.0
11/13/2008	<0.010	<0.010	<0.025			

(from...QA xls/Blanks)

Appendix L. Manure Applied

Table L.1. Summary of manure total nitrogen and inorganic nitrogen applied to the study field from 2005 through 2008.

Date	Total N applied (lb/acre)	Annual Total N applied (lb/year)	Chloride applied (lb/acre)	Annual total chloride applied (lb/acre)
2/18/2005	93		39	
5/13/2005	179		48	
<i>6/27/2005</i>	<i>41</i>			
8/9/2005	136 ⁺		51	
8/31/2005	195	644	60	198
4/27/2006	171		45	
5/25/2006	31			
7/11/2006	102		37	
10/5/2006	90	394	29	111
3/14/2007	109 ⁺		40	
5/18/2007	132		24	
6/26/2007	48			
8/6/2007	69		33	
9/7/2007	77	434	23	120
3/10/2008	171		39	
5/20/2008	193		52	
6/23/2008	145		40	
7/31/2008	98		32	
9/13/2008	108	715	42	205

Bold represent inorganic fertilizer applications.

Italic represents an estimate based on amount of manure applied and Agros field meter ammonia result, because a sample could not be collected.

Bold italic is the estimated chloride applied as the mean ratio of chloride to nitrogen in all applications times lb/acre nitrogen applied.

⁺: Relative standard deviation of duplicates exceeded 7%. See Appendix Table K.1 for details.

(My Documents\Data\Nooksack 2\Report\Final report 2010\Manure_03_31_10.xlsx—Appendix tab.)

Table L.2. Nitrogen and chloride data for manure.

							Average					Manure	Manure	Manure
			Solids	Total N	Avg Total N	Ammonia N	Ammonia N	Chloride	Average Chloride	Rate Applied	Rate Applied	Ammonia N Application Rate	Total N Application Rate	Chloride Application Rate
Sample Number	Date	Application Method	%	lbs/1,000 gallons	lbs/1,000 gallons	lbs/1,000 gallons	lbs/1,000 gallons	mg/L	mg/L	Gal/Acre	Inch/Acre	lbs/acre	lbs/acre	lbs/acre
DOE M3	2/18/2005	Lagoon	1.63	10.2	10.6	8.69	8.24			8,967	0.330	73.8	95.3	
DOE M4	2/18/2005	Lagoon	1.77	11.1		7.78				8,967	0.330			
DOE M5	2/18/2005	Aerator	1.37	9.35	10.2	8.51	8.02			8,967	0.330	71.9	91.5	
DOE M6	2/18/2005	Aerator	1.39	11.1		7.52		525		8,967	0.330			39.2
DOE M7	5/13/2005	Aerator	3.52	17.9	17.85	11.8	11.8	579		10,000	0.368	118	179	48.2
DOE M8	5/13/2005	Aerator	3.44	17.9		11.4								
	6/27/2005	Injector	No notification, ammonia sample from Agros field meter.							8,876	0.327	27	41	
DOE M9	8/9/2005	Injector	1.69	11.1	11.1	8.51	8.18	500		12,309	0.453	101	136	51.2
DOE M10	8/9/2005	Injector	1.69	11.1		7.85								
DOE M12	8/31/2005	Aerator	6.97	23.0	24.7	12.6	12.1	911		7,920	0.292	95.7	195	60.1
DOE M13	8/31/2005	Aerator	6.85	26.4		11.5								
DOE M15	4/27/2006	Aerator	4.87	18.7	19.6	7.71	7.58	617	572	8,750	0.322	66.3	171	44.9
DOE M16	4/27/2006	Aerator	5.24	20.4		7.45		526		8,750	0.322			
DOE M17	7/11/2006	Aerator	2.37	11.1	10.6	4.46	4.20	466		9,622	0.354	40.4	102	37.3
DOE M18	7/11/2006	Aerator	2.27	10.2		3.94				9,622	0.354			
DOE M20	10/5/2006	Aerator	4.22	19.55	20.0	7.64	7.60			4,500	0.166	34.2	89.9	
DOE M21	10/5/2006	Aerator	4.80	20.4		7.55				4,500				
DOE M22	10/5/2006	Aerator	4.29	19.55		7.53				4,500				
DOE M23	3/14/2007	Aerator	3.65	14.5	13.6	6.02	6.11	600	508	8,000	0.295	48.8	109	40.0
DOE M24	3/14/2007	Aerator	3.48	12.8		6.19		415		8,000	0.295			
DOE M26	5/18/2007	Aerator	4.11	18.7	18.3	7.07	7.07	406	406	7,200	0.265	50.9	132	24.3
DOE M27	5/18/2007	Aerator	3.33	17.9										
DOE M29	8/6/2007	Aerator	1.11	7.65	7.23	2.72	2.49	409	413	9,566	0.352	23.8	69.1	32.9
DOE M30	8/6/2007	Aerator	1.04	6.80		2.26		416		9,566	0.352			
DOE M31	9/7/2007	Injector	3.2	11.9	12.8	3.32	3.46	463	473	6,000	0.221	20.7	76.5	23.1
DOE M32	9/7/2007	Injector	2.95	13.6		3.59		483		6,000	0.221			
DOE M33	3/10/2008	Aerator	4.28	19.9	19.5	6.55	6.58	530	530	8,750	0.322	57.5	171	38.6
DOE M34	3/10/2008	Aerator	4.11	19.1		6.60								
DOE M36	3/18/2008	Solids	18.0	6.80		1.20		Applied to the edges of the field and a small amount on the field.						
DOE M37	5/20/2008	Aerator	2.85	16.6	16.6	5.76	5.84	530	535	11,650	0.429	68.0	193	51.9
DOE M38	5/20/2008	Aerator	3.41	16.6		5.91		540		11,650				
DOE M40	6/23/2008	Aerator	5.32	17.4	17.0	9.16	9.365	560	565	8,500	0.313	79.6	145	40.0
DOE M41	6/23/2008	Aerator	5.19	16.6		9.57		570		8,500				
DOE M42	7/31/2008	Injector	1.30	7.47	7.89	4.42	4.36	310	310	12,430	5.771	54.2	98.0	32.1
DOE M43	7/31/2008	Injector	1.32	8.30		4.30		310		12,430				
DOE M44	9/13/2008	Aerator	4.36	17.4	16.6	8.62	8.67	780	780	6,500	3.018	56.3	108	42.2
DOE M45	9/13/2008	Aerator	4.46	15.8		8.71		780		6,500				

Bold: Estimate, no laboratory analyses.

(Y:Shared files/LordBarb-Manure study/Manure_03_31-10.xlsx, WSU N data tab

Appendix M. Irrigation Data

Table M.1. Irrigation water quality data and quality assurance results.

Date	Sample Number	Average Nitrite+Nitrate-N			Average Ammonia-N			Average TPN		
		Nitrite+Nitrate-N (mg/L)	Nitrite+Nitrate-N (mg/L)	Relative % Difference (%)	Ammonia-N (mg/L)	Ammonia-N (mg/L)	Relative % Difference (%)	TPN ¹ (mg/L)	TPN (mg/L)	Relative % Difference (%)
9/15/2005	1	0.01	0.0115	26.1	---	---	---	---	---	---
9/15/2005	2	0.013								
10/15/2005	3	0.029	0.032	18.8	---	---	---	---	---	---
10/15/2005	4	0.035								
7/22/2006	5	0.073	0.079	15.2	---	---	---	---	---	---
7/22/2006	6	0.085								
8/22/2006	7	0.049	0.048	4.2	---	---	---	---	---	---
8/22/2006	8	0.047								
7/17/2007	9	0.015	0.0155	6.5	---	---	---	---	---	---
7/17/2007	10	0.016								
8/23/2007	11	0.017	0.0155	19.4	---	---	---	---	---	---
8/23/2007	12	0.014								
9/12/2007	13	0.021	0.0205	4.9	0.794	0.805	2.6	1.37	1.37	0.0
9/12/2007	14	0.02			0.815			1.37		
7/8/2008	15	0.039	0.038	5.3	0.743	0.740	0.8	1.37	1.30	10.8
7/8/2008	16	0.037			0.737			1.23		
8/16/2008	17	0.033	0.033	0.0	0.853	0.841	2.9	1.49	1.30	30.1
8/16/2008	18	0.033			0.829			1.10		

¹ Total persulfate nitrogen

(My Doc's/Data/Nooksack 2/Report/final report 2010/irrigation water.xlsx—Quality tab-- based on Lynn's spreadsheet)

Table M. 3. Nitrogen input from irrigation water.

Year	Gallons applied	N loading ¹
2005 ²	66,130.00	11.51
2006	154,671.00	26.91
2007	147,282.00	25.63
2008	119,909.00	20.86

¹ Assumes the average total nitrogen concentration (1.3 mg/L) in all irrigation water, which converts to 1.74×10^{-4} lb N/gallon.

² This is an estimate (Van Wieringen and Harrison, 2009).
(...Irrigation water.xlsx—N loading tab)

Appendix N. Grass Crop Results

		Wet Weight	Dry Matter	Dry Weight	Swath Dimensions	Sampling Area	Conversion Factor	Dry Matter Yield	Average Dry Matter Yield	Crude Protein	Average Crude Protein	Standard Deviation Crude Protein	Coefficient of Variation for Crude Protein	Nitrate Ion	Nitrogen Harvested	Average Nitrogen Harvested
Sample	Date	lbs	%	lbs	8 5 x 5 ft	ft ²	No of sample areas/acre	tons/acre	tons/acre	%	%	%	%	%	lbs/acre	lbs/acre
DOE-1	10/4/2004	55 85	13 03	7 28	42 5	67 5	645 3	2 35	1 68	24 4					183 3	131 1
DOE-2	10/4/2004	26 65	16 73	4 46	42 5	67 5	645 3	1 44		24 4					112 3	
DOE-3	10/4/2004	27 2	16 76	4 56	42 5	67 5	645 3	1 47		24 4					114 8	
DOE-4	10/4/2004	23 55	19 23	4 53	42 5	67 5	645 3	1 46		24 4					114 1	
DOE-5	4/28/2005	2 5	17 67	0 44			10,890	2 41	2 33	15 7	16 74	0 820	4 90	0 31	120 8	124 52
DOE-6	4/28/2005	2 65	16 95	0 45			10,890	2 45		16 7					130 7	
DOE-7	4/28/2005	2 5	17 65	0 44			10,890	2 40		16 7					128 4	
DOE-8	4/28/2005	2 35	15 2	0 36			10,890	1 94		18					112 0	
DOE-9	4/28/2005	2 6	17 37	0 45			10,890	2 46		16 6					130 6	
DOE-10	6/12/2005	9 65	24 26	2 34	40	77 5	562	0 66	1 32	21 6	18 38	1 871	10 18	0 34	45 5	76 25
DOE-11	6/12/2005	16 15	26 24	4 24	40	77 5	562	1 19		16 7					63 6	
DOE-12	6/12/2005	28 5	22 65	6 46	40	77 5	562	1 81		17 8					103 3	
DOE-13	6/12/2005	23 95	22 47	5 38	40	77 5	562	1 51		18					87 1	
DOE-14	6/12/2005	22 95	22 25	5 11	40	77 5	562	1 43		17 8					81 7	
DOE-15	7/17/2005	1 55	19 32	0 30			10,890	1 63	1 75	14 2				0 14	74 1	79 48
DOE-16	7/17/2005	0 95	26 22	0 25			10,890	1 36		14 2					61 6	
DOE-17	7/17/2005	1 7	18 31	0 31			10,890	1 69		14 2					77 0	
DOE-18	7/17/2005	1 4	19 06	0 27			10,890	1 45		14 2					66 0	
DOE-19	7/17/2005	2 2	21 8	0 48			10,890	2 61		14 2					118 7	
DOE-20	7/17/2005	1 3	19 72	0 26			10,890	1 40	1 48	15 1				0 15	67 4	71 62
DOE-21	7/17/2005	1 4	20 56	0 29			10,890	1 57		15 1					75 7	
DOE-22	7/17/2005	1 1	21 96	0 24			10,890	1 32		15 1					63 6	
DOE-23	7/17/2005	1 55	17 76	0 28			10,890	1 50		15 1					72 4	
DOE-24	7/17/2005	1 5	20	0 30			10,890	1 63		15 1					78 9	
DOE-25	8/25/2005	1	18 06	0 18			10,890	0 98	0 93	20 8				0 62	65 5	62 19
DOE-26	8/25/2005	0 85	21 85	0 19			10,890	1 01		20 8					67 3	

DOE-27	8/25/2005	0 4	22 51	0 09			10,890	0 49		20 8				32 6	
DOE-28	8/25/2005	0 5	23 27	0 12			10,890	0 63		20 8				42 2	
DOE-29	8/25/2005	1 35	21 13	0 29			10,890	1 55		20 8				103 4	
DOE-30	8/25/2005	0 75	19 82	0 15			10,890	0 81	0 83	22 4			0 72	58 0	59 85
DOE-31	8/25/2005	1 4	16 54	0 23			10,890	1 26		22 4				90 4	
DOE-32	8/25/2005	0 55	21 79	0 12			10,890	0 65		22 4				46 8	
DOE-33	8/25/2005	0 65	20 34	0 13			10,890	0 72		22 4				51 6	
DOE-34	8/25/2005	0 5	26 88	0 13			10,890	0 73		22 4				52 5	
DOE-35	12/13/2005	1 25	23 43	0 29			10,890	1 59	1 29	21 9			0 01	111 8	90 57*
DOE-36	12/13/2005	1 45	11 09	0 16			10,890	0 88		21 9				61 4	
DOE-37	12/13/2005	1 4	11 39	0 16			10,890	0 87		21 9				60 8	
DOE-38	12/13/2005	1 95	17 78	0 35			10,890	1 89		21 9				132 3	
DOE-39	12/13/2005	2 35	9 66	0 23			10,890	1 24		21 9				86 6	
DOE-40	12/13/2005	1 6	12 29	0 20			10,890	1 07	1 66	21 2			0 63	72 6	112 85*
DOE-41	12/13/2005	1 85	18 60	0 34			10,890	1 87		21 2				127 1	
DOE-42	12/13/2005	1 7	20 61	0 35			10,890	1 91		21 2				129 4	
DOE-43	12/13/2005	1 6	20 52	0 33			10,890	1 79		21 2				121 3	
DOE-44	12/13/2005	1 65	18 68	0 31			10,890	1 68		21 2				113 8	
DOE 45	C5118	1 65	15 65	0 26			10,890	1 41	1 90	19 7			0 48	88 7	119 48
DOE 46	C5119	2 7	16 32	0 44			10,890	2 40		19 7				151 3	
DOE 47	C5120	3	14 80	0 44			10,890	2 42		19 7				152 4	
DOE 48	C5121	2 15	14 62	0 31			10,890	1 71		19 7				107 9	
DOE 49	C5122	1 95	14 52	0 28			10,890	1 54		19 7				97 2	
DOE 50	C5123	1 6	17 29	0 28			10,890	1 51	1 95	19 6			0 38	94 5	122 10
DOE 51	C5124	2 5	17 86	0 45			10,890	2 43		19 6				152 4	
DOE 52	C5125	2 05	17 19	0 35			10,890	1 92		19 6				120 3	
DOE 53	C5126	2 1	16 72	0 35			10,890	1 91		19 6				119 9	
DOE 54	C5127	2 15	16 80	0 36			10,890	1 97		19 6				123 3	

DOE 55	5/25/2006	0 924	14 61	0 13			10,890	0 73	0 95	25 7				1 78	60 4	78 36
DOE 56	5/25/2006	1 474	15 97	0 24			10,890	1 28		25 7					105 4	
DOE 57	5/25/2006	1 21	15 14	0 18			10,890	1 00		25 7					82 0	
DOE 58	5/25/2006	0 924	15 64	0 14			10,890	0 79		25 7					64 7	
DOE 59	5/25/2006	1 474	12 00	0 18			10,890	0 96		25 7					79 2	
DOE 60	5/25/2006	1 606	13 72	0 22			10,890	1 20	1 15	23 8				1 56	91 3	87 67
DOE 61	5/25/2006	1 672	14 99	0 25			10,890	1 36		23 8					103 9	
DOE 62	5/25/2006	1 298	15 80	0 21			10,890	1 12		23 8					85 0	
DOE 63	5/25/2006	1 474	14 27	0 21			10,890	1 15		23 8					87 2	
DOE 64	5/25/2006	1 034	16 52	0 17			10,890	0 93		23 8					70 8	
DOE 65	7/5/2006	1 25	20 18	0 25			10,890	1 37	1 49	17 3				0 52	76 0	82 36*
DOE 66	7/5/2006	17 25	25 20	4 35	40	77 5	562	1 22		17 3					67 6	
DOE 67	7/5/2006	20 65	24 21	5 00	40	77 5	562	1 40		17 3					77 8	
DOE 68	7/5/2006	25 6	23 67	6 06	40	77 5	562	1 70		17 3					94 3	
DOE 69	7/5/2006	29 45	20 98	6 18	40	77 5	562	1 74		17 3					96 1	
DOE 70	7/5/2006	24 35	23 58	5 74	40	77 5	562	1 61	1 37	18 7				0 84	96 5	81 96*
DOE 71	7/5/2006	21 75	26 60	5 79	40	77 5	562	1 63		18 7					97 3	
DOE 72	7/5/2006	10 85	33 50	3 63	40	77 5	562	1 02		18 7					61 1	
DOE 73	7/5/2006	17 15	27 55	4 72	40	77 5	562	1 33		18 7					79 4	
DOE 74	7/5/2006	16 1	27 85	4 48	40	77 5	562	1 26		18 7					75 4	
DOE 75	8/15/2006	1 166	17 48	0 20			10,890	1 11	0 96	21 6				0 94	76 7	66 62
DOE 76	8/15/2006	0 902	20 84	0 19			10,890	1 02		21 6					70 7	
DOE 77	8/15/2006	0 704	22 20	0 16			10,890	0 85		21 6					58 8	
DOE 78	8/15/2006	0 814	21 03	0 17			10,890	0 93		21 6					64 4	
DOE 79	8/15/2006	0 66	25 13	0 17			10,890	0 90		21 6					62 4	
DOE 80	8/15/2006	1 254	19 30	0 24			10,890	1 32	1 19	22 6				0 9	95 3	86 11
DOE 81	8/15/2006	0 968	23 09	0 22			10,890	1 22		22 6					88 0	
DOE 82	8/15/2006	1 078	20 25	0 22			10,890	1 19		22 6					86 0	
DOE 83	8/15/2006	1 21	18 54	0 22			10,890	1 22		22 6					88 3	
DOE 84	8/15/2006	0 924	20 05	0 19			10,890	1 01		22 6					73 0	
DOE 85	9/27/2006	1 3112	14 75	0 19			10,890	1 05	1 06	19 5				0 61	65 7	65 95

DOE 86	9/27/2006	0 9108	20 70	0 19			10,890	1 03		19 5				64 1	
DOE 87	9/27/2006	1 3464	18 02	0 24			10,890	1 32		19 5				82 4	
DOE 88	9/27/2006	1 056	17 95	0 19			10,890	1 03		19 5				64 4	
DOE 89	9/27/2006	0 9812	15 93	0 16			10,890	0 85		19 5				53 1	
DOE 90	9/27/2006	1 4124	16 24	0 23			10,890	1 25	1 01	21 4			0 71	85 5	69 05
DOE 91	9/27/2006	1 012	17 93	0 18			10,890	0 99		21 4				67 7	
DOE 92	9/27/2006	0 9064	19 88	0 18			10,890	0 98		21 4				67 2	
DOE 93	9/27/2006	1 2584	14 20	0 18			10,890	0 97		21 4				66 6	
DOE 94	9/27/2006	0 8888	17 57	0 16			10,890	0 85		21 4				58 2	
DOE 95	5/6/2007	2 65	14 78	0 39			10,890	2 13	2 53	18 2			0 5	124 2	147 47
DOE 96	5/6/2007	3 3	15 92	0 53			10,890	2 86		18 2				166 6	
DOE 97	5/6/2007	4 15	13 26	0 55			10,890	3 00		18 2				174 6	
DOE 98	5/6/2007	2 9	15 03	0 44			10,890	2 37		18 2				138 2	
DOE 99	5/6/2007	2 85	14 80	0 42			10,890	2 30		18 2				133 8	
DOE 100	5/6/2007	4 55	15 24	0 69			10,890	3 78	3 10	15 9			0 29	192 1	157 61
DOE 101	5/6/2007	3 7	17 31	0 64			10,890	3 49		15 9				177 4	
DOE 102	5/6/2007	3 1	18 12	0 56			10,890	3 06		15 9				155 6	
DOE 103	5/6/2007	2 75	17 52	0 48			10,890	2 62		15 9				133 5	
DOE 104	5/6/2007	3 3	14 16	0 47			10,890	2 54		15 9				129 4	
DOE 105	6/14/2007	1 75	15 19	0 27			10,890	1 45	1 46	21 1			1 04	97 7	98 90
DOE 106	6/14/2007	1 25	23 81	0 30			10,890	1 62		21 1				109 4	
DOE 107	6/14/2007	1 05	19 77	0 21			10,890	1 13		21 1				76 3	
DOE 108	6/14/2007	1 65	18 20	0 30			10,890	1 63		21 1				110 4	
DOE 109	6/14/2007	1 6	17 11	0 27			10,890	1 49		21 1				100 6	
DOE 110	6/14/2007	1 5	19 45	0 29			10,890	1 59	1 30	19 5			0 64	99 1	81 33
DOE 111	6/14/2007	0 8	20 34	0 16			10,890	0 89		19 5				55 3	
DOE 112	6/14/2007	0 7	20 11	0 14			10,890	0 77		19 5				47 8	
DOE 113	6/14/2007	1 9	16 51	0 31			10,890	1 71		19 5				106 6	
DOE 114	6/14/2007	1 6	17 99	0 29			10,890	1 57		19 5				97 8	
DOE 115	7/30/2007	1 2	22 80	0 27			10,890	1 49	1 29	19 4			0 6	92 5	79 95
DOE 116	7/30/2007	1 4	19 52	0 27			10,890	1 49		19 4				92 4	
DOE 117	7/30/2007	1 05	20 14	0 21			10,890	1 15		19 4				71 5	
DOE 118	7/30/2007	1 3					10,890			19 4					
DOE 119	7/30/2007	0 95	19 76	0 19			10,890	1 02		19 4				63 5	
DOE 120	7/30/2007	1 55	17 12	0 27			10,890	1 45	1 36	19 7			0 91	91 1	85 85

DOE 120	7/30/2007	1 55	17 12	0 27			10,890	1 45	1 36	19 7				0 91	91 1	85 85
DOE 121	7/30/2007	1 6	19 44	0 31			10,890	1 69		19 7					106 8	
DOE 122	7/30/2007	0 9	22 95	0 21			10,890	1 12		19 7					70 9	
DOE 123	7/30/2007	1 15	21 32	0 25			10,890	1 34		19 7					84 2	
DOE 124	7/30/2007	1	22 22	0 22			10,890	1 21		19 7					76 3	
DOE 125	8/28/2007	0 95	16 27	0 15			10,890	0 84	0 89	21 7				0 33	58 5	62 07
DOE 126	8/28/2007	0 65	22 28	0 14			10,890	0 79		21 7					54 8	
DOE 127	8/28/2007	0 95	22 22	0 21			10,890	1 15		21 7					79 8	
DOE 128	8/28/2007	0 85	19 72	0 17			10,890	0 91		21 7					63 4	
DOE 129	8/28/2007	0 7	20 38	0 14			10,890	0 78		21 7					53 9	
DOE 130	8/28/2007	1 6	13 85	0 22			10,890	1 21	0 82	23 7				0 44	91 5	61 89
DOE 131	8/28/2007	0 6	20 16	0 12			10,890	0 66		23 7					49 9	
DOE 132	8/28/2007	0 8	21 22	0 17			10,890	0 92		23 7					70 1	
DOE 133	8/28/2007	0 85	19 68	0 17			10,890	0 91		23 7					69 1	
DOE 134	8/28/2007	0 3	23 26	0 07			10,890	0 38		23 7					28 8	
DOE 135	10/10/2007	1 3	13 56	0 18			10,890	0 96	0 98	25 3				0 71	77 7	79 72
DOE 136	10/10/2007	0 9	16 56	0 15			10,890	0 81		25 3					65 7	
DOE 137	10/10/2007	1 75	16 66	0 29			10,890	1 59		25 3					128 5	
DOE 138	10/10/2007	1 4	11 47	0 16			10,890	0 87		25 3					70 8	
DOE 139	10/10/2007	1	12 67	0 13			10,890	0 69		25 3					55 9	
DOE 140	10/10/2007	1 2	10 59	0 13			10,890	0 69	0 71	26 2				0 89	58 0	59 69
DOE 141	10/10/2007	1 1	15 27	0 17			10,890	0 91		26 2					76 7	
DOE 142	10/10/2007	0 7	17 07	0 12			10,890	0 65		26 2					54 5	
DOE 143	10/10/2007	1 15	13 72	0 16			10,890	0 86		26 2					72 0	
DOE 144	10/10/2007	0 6	13 58	0 08			10,890	0 44		26 2					37 2	
DOE 145	5/9/2008	1 9	18 41	0 35			10,890	1 90	1 87	17 5				0 12	106 6	104 74
DOE 146	5/9/2008	2 1	17 87	0 38			10,890	2 04		17 5					114 4	
DOE 147	5/9/2008	1 7	19 26	0 33			10,890	1 78		17 5					99 8	
DOE 148	5/9/2008	2 05	17 05	0 35			10,890	1 90		17 5					106 6	
DOE 149	5/9/2008	2 25	14 02	0 32			10,890	1 72		17 5					96 2	
DOE 150	5/9/2008	2 35	17 16	0 40			10,890	2 20	2 14	18 4				0 18	129 3	126 11
DOE 151	5/9/2008	2 05	17 62	0 36			10,890	1 97		18 4					115 8	
DOE 152	5/9/2008	2 25	19 87	0 45			10,890	2 43		18 4					143 3	

DOE 153	5/9/2008	1 95	16 82	0 33			10,890	1 79		18 4				105 2	
DOE 154	5/9/2008	2 25	18 99	0 43			10,890	2 33		18 4				137 0	
DOE 155	6/16/2008	1 6	14 91	0 24			10,890	1 30	1 14	21 3			0 95	88 5	78 03
DOE 156	6/16/2008	1	20 21	0 20			10,890	1 10		21 3				75 0	
DOE 157	6/16/2008	1 15	17 83	0 21			10,890	1 12		21 3				76 1	
DOE 158	6/16/2008	1 25	16 66	0 21			10,890	1 13		21 3				77 3	
DOE 159	6/16/2008	1 15	17 15	0 20			10,890	1 07		21 3				73 2	
DOE 160	6/16/2008	1 4	16 32	0 23			10,890	1 24	1 21	22 2			0 87	88 4	85 90
DOE 161	6/16/2008	1 75	22 96	0 40			10,890	2 19		22 2				155 4	
DOE 162	6/16/2008	0 6	19 36	0 12			10,890	0 63		22 2				44 9	
DOE 163	6/16/2008	1 1	17 94	0 20			10,890	1 07		22 2				76 3	
DOE 164	6/16/2008	1 1	15 14	0 17			10,890	0 91		22 2				64 4	
DOE 165	7/21/2008	1 1	13 99	0 15			10,890	0 84	1 01	21 7			0 62	58 2	69 91
DOE 166	7/21/2008	0 7	20 94	0 15			10,890	0 80		21 7				55 4	
DOE 167	7/21/2008	1 15	20 73	0 24			10,890	1 30		21 7				90 1	
DOE 168	7/21/2008	1 05	17 40	0 18			10,890	0 99		21 7				69 1	
DOE 169	7/21/2008	1 1	18 44	0 20			10,890	1 10		21 7				76 7	
DOE 170	7/21/2008	1 5	14 31	0 21			10,890	1 17	1 10	19 3			0 42	72 2	68 00
DOE 171	7/21/2008	0 85	21 37	0 18			10,890	0 99		19 3				61 1	
DOE 172	7/21/2008	1 15	22 01	0 25			10,890	1 38		19 3				85 1	
DOE 173	7/21/2008	0 95	19 06	0 18			10,890	0 99		19 3				60 9	
DOE 174	7/21/2008	0 8	22 58	0 18			10,890	0 98		19 3				60 7	
DOE 175	9/2/2008	1	10 43	0 10			10,890	0 57	0 95	24 4			0 12	44 3	74 22
DOE 176	9/2/2008	1 6	12 55	0 20			10,890	1 09		24 4				85 4	
DOE 177	9/2/2008	1 75	10 71	0 19			10,890	1 02		24 4				79 7	
DOE 178	9/2/2008	1 25	10 92	0 14			10,890	0 74		24 4				58 0	
DOE 179	9/2/2008	1 8	13 55	0 24			10,890	1 33		24 4				103 7	
DOE 180	9/2/2008	1 55	11 76	0 18			10,890	0 99	0 79	23 5			0 16	74 6	59 23
DOE 181	9/2/2008	1 25	10 52	0 13			10,890	0 72		23 5				53 8	
DOE 182	9/2/2008	1 15	13 67	0 16			10,890	0 86		23 5				64 4	
DOE 183	9/2/2008	0 95	10 72	0 10			10,890	0 55		23 5				41 7	
DOE 184	9/2/2008	1 6	9 41	0 15			10,890	0 82		23 5				61 6	
DOE 185	10/21/2008	9 2	16 83	1 55	40	72 5	601	0 47	0 78	23 7			0 6	35 3	58 84
DOE 186	10/21/2008	19 35	18 01	3 49	40	72 5	601	1 05		23 7				79 4	
DOE 187	10/21/2008	11 5	23 14	2 66	40	72 5	601	0 80		23 7				60 7	
DOE 188	10/21/2008	11 75	17 52	2 06	40	72 5	601	0 95		23 7				46 9	
DOE 189	10/21/2008	16 15	19 53	3 15	40	72 5	601	0 95		23 7				71 9	
DOE 190	10/21/2008	14 15	16 00	2 26	40	72 5	601	0 68	0 75	25 8			0 61	56 2	61 93
DOE 191	10/21/2008	14 25	15 03	2 14	40	72 5	601	0 64		25 8				53 1	
DOE 192	10/21/2008	19 35	19 51	3 77	40	72 5	601	1 13		25 8				93 7	

DOE 187	10/21/2008	11 5	23 14	2 66	40	72 5	601	0 80		23 7					60 7	
DOE 188	10/21/2008	11 75	17 52	2 06	40	72 5	601	0 62		23 7					46 9	
DOE 189	10/21/2008	16 15	19 53	3 15	40	72 5	601	0 95		23 7					71 9	
DOE 190	10/21/2008	14 15	16 00	2 26	40	72 5	601	0 68	0 75	25 8				0 61	56 2	61 93
DOE 191	10/21/2008	14 25	15 03	2 14	40	72 5	601	0 64		25 8					53 1	
DOE 192	10/21/2008	19 35	19 51	3 77	40	72 5	601	1 13		25 8					93 7	
DOE 193	10/21/2008	9 8	17 89	1 75	40	72 5	601	0 53		25 8					43 5	
DOE 194	10/21/2008	14 55	17 51	2 55	40	72 5	601	0 77		25 8					63 2	
* Relative standard deviation of dry weight results exceeded 10%.																

(Nooksack 2\Report\final report 2010\Grass.xlsx—Lynn's table Appendix)

Appendix O. Soil Results.

Table O.1. Soil Nitrate, Soil Temperature, and Soil Moisture Data, 2004 through 2008.

	Soil Nitrate		Soil Temperature	Soil Moisture			Soil Nitrate	Soil Temperature	Soil Moisture
Date	(mg/kg at 1-foot)		(Degrees C at 6-inches)	(% of dry weight at 1-foot)		Date	(mg/kg at 1-foot)	(Degrees C at 6-inches)	(% of dry weight at 1-foot)
8/25/2004	51.5			33.3		11/1/2006	30.5		30.7
9/9/2004	43.0		15.6	28.6		11/8/2006	60.0		32.3
9/17/2004	28.5		12.2	34.1		11/15/2006	15.5	P	6.1
10/1/2004	19.0	P	11.1	28.5		11/21/2006	13.5		33.4
10/12/2004	23.0		12.2	34.3		12/20/2006	14.0		34.1
10/22/2004	26.5		8.3	36.6		1/26/2007	11.9		35.1
11/5/2004	23.0		5.6	37.4		2/23/2007	10.0		34.4
11/12/2004	22.5		4.4	35.1		3/23/2007	6.1		54.7
11/19/2004	18.5		3.3	37.3		4/25/2007	11.2	P	38.4
12/3/2004	16.0		2.2	38.3		5/16/2007	18.4		28.6
2/22/2005	16.5		0.0	34.7		6/26/2007	23.5		27.1
3/25/2005	14.5		5.6	34.0		7/24/2007	22.6		32.8
4/28/2005	16.0		10.0	25.9		8/7/2007	17.5		22.8
5/27/2005	31.5		14.4	24.6		8/15/2007	20.7		19.7
6/29/2005	17.0	P	15.6	22.8		8/21/2007	19.9		22.2
7/28/2005	5.5		17.8	14.3		8/28/2007	18.3		24.8
8/5/2005	5.0		17.8	12.7		9/5/2007	15.8		23.9
8/11/2005	19.0		17.8	17.8		9/11/2007	25.3		22.8
8/17/2005	29.5	P	16.7	23.0		9/18/2007	15.4		24.5
8/24/2005	21.0	P	14.4	20.2		9/25/2007	14.7	P	28.4
8/31/2005	28.0		15.6	19.9		10/2/2007	14.4		40.0
9/7/2005	30.0	P	12.8	20.5		10/9/2007	16.9		33.9
9/13/2005	26.5	P	12.2	18.0		10/16/2007	18.8		35.5
9/21/2005	21.0		9.4	16.5		10/23/2007	14.7		36.5
9/27/2005	16.5	P	12.8	15.2		10/30/2007	11.8		38.9
10/4/2005	15.5	P	9.4	29.0		11/6/2007	11.5		35.3
10/11/2005	16.0		5.6	32.2		11/13/2007	10.2		36.3
10/18/2005	11.5	P	7.2	35.7		11/20/2007	11.0	P	36.8
10/25/2005	22.0	P	6.7	35.6		11/27/2007	11.9		36.9
11/1/2005	11.5	P	6.1	43.4		12/21/2007	18.0		37.0
11/10/2005	5.5	P	3.3	45.6		1/22/2008	20.5		37.5
11/15/2005	10.0		0.6	36.3		2/22/2008	10.6		35.2
11/21/2005	16.5		-1.7	35.6		3/18/2008	14.1		39.3
11/29/2005	14.5		-5.0	43.4		4/22/2008	17.4		33.4
12/16/2005	17.0		1.1	36.4		5/27/2008	29.3		35.8
1/19/2006	10.0		5.6	41.5		6/25/2008	34.3		29.6
2/22/2006	13.0		2.2	26.3		7/23/2008	17.2		25.9
3/30/2006	12.5		7.2	32.1		8/6/2008	29.7	P	25.3
4/27/2006	13.5		11.1	28.2		8/15/2008	25.4		29.2
5/25/2006	16.0		14.4	19.9		8/22/2008	22.3		32.9
6/27/2006	22.0		17.2	15.4		8/29/2008	21.1	P	38.9
7/24/2006	40.0		21.1	15.6		9/5/2008	20.9		32.5
8/3/2006	30.5		16.7	22.5		9/12/2008	29.5		29.7
8/11/2006	26.0		16.1	21.4		9/19/2008	35.9		30.5
8/22/2006	20.5		18.3	14.4		9/26/2008	41.2		33.2
8/30/2006	21.0	P	14.4	26.6		10/3/2008	26.5		32.0
9/6/2006	22.5		8.9	22.7		10/10/2008	21.6	P	32.7
9/13/2006	17.0		8.3	22.8		10/17/2008	26.9	P	41.0
9/20/2006	15.5		29.9	29.9		10/24/2008	30.8	P	36.3
9/27/2006	23.0		27.2	27.2		10/31/2008	29.9		37.0
10/4/2006	17.0		25.5	25.5		11/7/2008	9.6		50.7
10/12/2006	18.0			24.0		11/14/2008	10.9		37.4
10/18/2006	25.0			28.8		11/21/2008	11.7		38.3
10/26/2006	29.0			30.3		11/28/2008			36.6

P: Results of duplicate samples on this date did not meet the 20% target for relative standard deviation.

Table O.2. Soil chemistry results.


	Phosphorus (Bray)	Potassium	Boron	Zinc	Mn	Cu	Fe	Ca	Mg	Na	S	Buffer pH	CEC	Total Bases	Base Saturation	pH	E.C.	Est Sat Paste E C	Organic Matter	Ammonium N
Date	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm		meq/100g	meq/100g	%	Std. Units	m.mhos/ cm	m.mhos/ cm	%	ppm
4/28/2005	216	625	0.3	8.5	7.6	4.0	128	9.0	3.0	0.20		6.7	18.9	13.8	72.8	6.3	0.20	0.52	7.2	
6/27/2006	198	432	0.2	7.0	5.1	3.6	101	7.7	2.9	0.20		6.4	21.7	11.9	55.0	6.0	0.24	0.62	7.0	16
4/25/2007	183	662	0.5	9.3	9.3	4.0	94	9.9	3.6	0.41		6.5	23.5		66.5	6.3	0.90		8.4	
4/22/2008	196	542	0.6	6.6	4.8	3.1	92	8.3	3.0	0.21	16	6.8	22.3	13	58.2	6.4	0.28	0.73	7.4	5.3

(My Doc's/Data/Nooksack 2/Report/Final report/ Soil raw data_06_10.xlsx—ions & organic matter

Appendix P. Grain Size Data from Monitoring Well Soil Samples

State of Washington Department of Ecology
Manchester Environmental Laboratory
7411 Beach Drive East
Port Orchard WA. 98366

June 21, 2005

Project: Manure as Fertilizer
Samples: 18-4080-94
Laboratory: Analytical Resources, Inc.
By: Pam Covey 

Case Summary

The sediment samples required Grain Size analyses using the ASTM D 422 method. The samples were received at the Manchester Environmental Laboratory and shipped to the contract lab on May 10, 2005 for Grain Size analyses. One sample was analyzed in triplicate and was within the QA limits.

The analyses were reviewed for qualitative and quantitative accuracy, validity and usefulness.

If you have any questions, please call me at 360-871-8827.



Analytical Resources, Incorporated
Analytical Chemists and Consultants

Client: Dept. of Ecology

Project No.: IA93

Client Project: Manure as Fertilizer

Case Narrative

1. The samples were submitted for grain size analysis according to ASTM methodology. Three samples were to be run for full sieve and hydrometer analysis and the rest for sieve only. A fourth sample was run for hydrometer by mistake.
2. The samples were run in batches; the sieve only samples were run together and the hydrometers were run together. One sample was selected for triplicate analysis by Ecology. The triplicate data is reported on the QA summary.
3. The samples were run according to ASTM D422, with an extra #140 sieve inserted into the sieve stack.
4. The data is provided in summary tables.
5. There were no other noted anomalies in the samples or methods on this project.

Approved by:

Title:

Harold Benning
Geotechnical Division Manager

Date:

6/1/05

4611 South 134th Place, Suite 100 • Tukwila WA 98168 • 206-695-6200 • 206-695-6201 fax



Washington State Dept. of Ecology
Manure as Fertilizer

Percent Retained in Each Size Fraction

Description	% Gravel	% Coarse Sand	% Medium Sand	% Fine Sand	% Very Coarse Silt	% Coarse Silt	% Medium Silt	% Fine Silt	% Fine Silt	% Very Fine Silt	% Clay
Particle Size (microns)	> 4750	4750-2000	2000-425	425-75	75-32	32-22	22-13	13-9	9-7	7-3.2	<3.2
184080	2.0	0.5	20.5	71.3	5.6						
184081	0.1	0.0	4.1	86.3	5.5						
184082	0.4	6.3	38.8	26.7	28.6						
184083	0.0	0.0	3.6	50.0	20.5	6.7	5.6	4.4	2.9	4.4	20.3
184084	0.0	0.1	5.0	85.2	9.7						
184085	0.0	0.1	0.3	22.6	9.8	4.5	9.0	5.2	5.2	9.0	34.4
184086	0.0	0.0	30.6	69.3	9.2						
184087	14.5	6.5	48.7	25.9	4.4						
184088	0.9	3.8	12.0	29.5	53.8						
184089	0.1	0.2	10.0	82.3	7.4						
184090	0.0	0.1	15.1	79.9	5.0						
184091	0.7	0.2	3.1	92.8	3.2						
184092A	0.0	0.0	0.1	1.9	18.6	9.3	11.0	6.7	5.8	11.5	35.4
184092B	0.0	0.0	0.1	3.2	16.1	9.9	11.3	7.2	9.0	9.0	34.0
184092C	0.0	0.0	0.2	2.7	17.7	9.0	11.7	7.2	8.3	10.5	34.3
184093	0.0	0.0	0.6	62.6	14.3	1.3	2.7	1.3	1.0	2.0	14.0
184094	0.3	0.2	5.7	88.8	8.0						

Key to description (Lab No.) and monitoring well ID's

Lab No.	Well	Depth (ft)
184082	AK0721	2.5-4
184083	AK0721	5-6.5
184084	AK0721	10-11.5
184080	AK0722	3-6.5
184081	AK0722	10-11.5
184085	AK0723	2.5-4
184086	AK0723	10-11.5
184087	AK0724	7.5-9
184088	AK0725	2.5-4
184089	AK0725	7.5-9
184090	AK0726	15-16.5
184091	AK0726	25-29.5
184092	AK0726	40-41.5
184093	AK0727	2.5-4
184094	AK0727	10-11.5

1893

PROJECT:	Washington State Dept. of Ecology	Project No.:	Manure as Fertilizer
ARI Triplicate Sample ID:	IA93M	Batch No.:	IA93 -01
Client Triplicate Sample ID:	184092	Page:	1 of 1

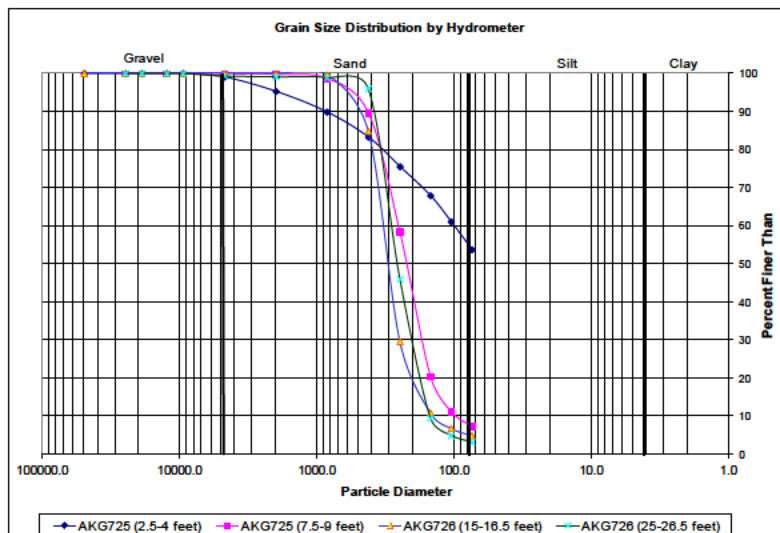
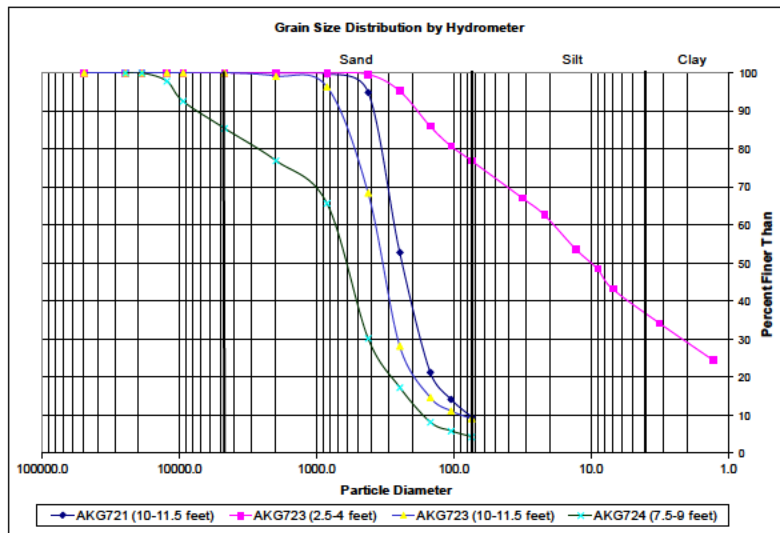
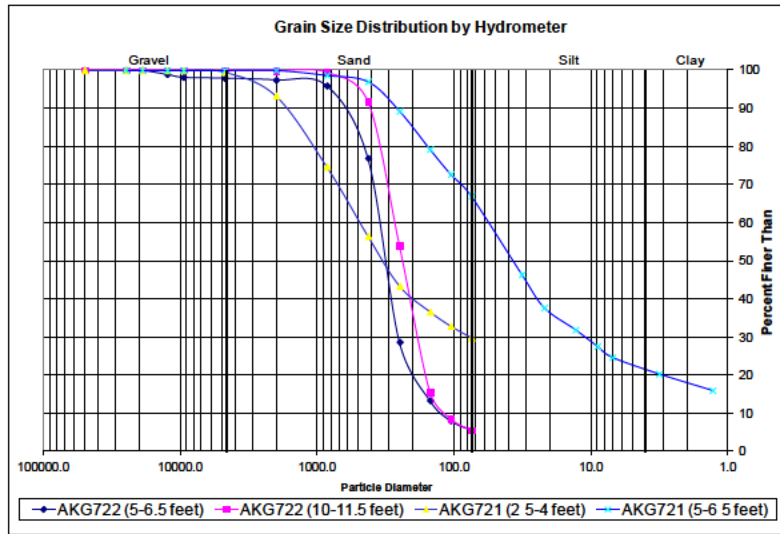
Relative Standard Deviation, By Size

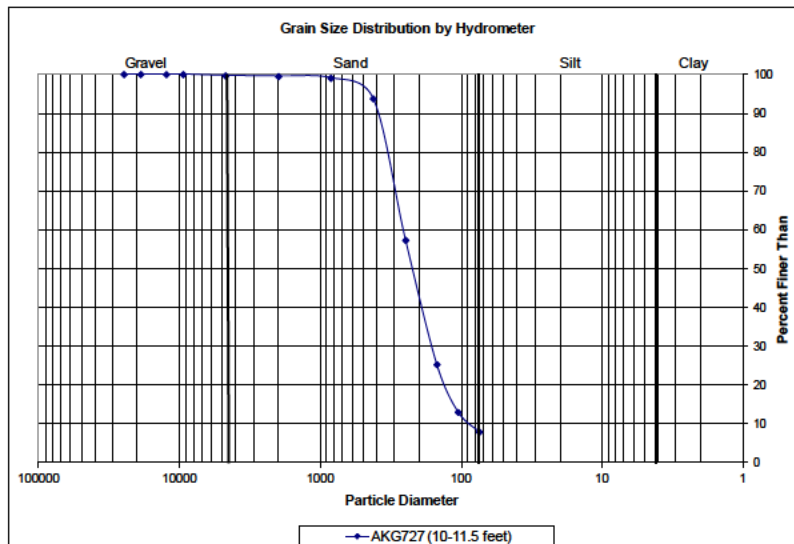
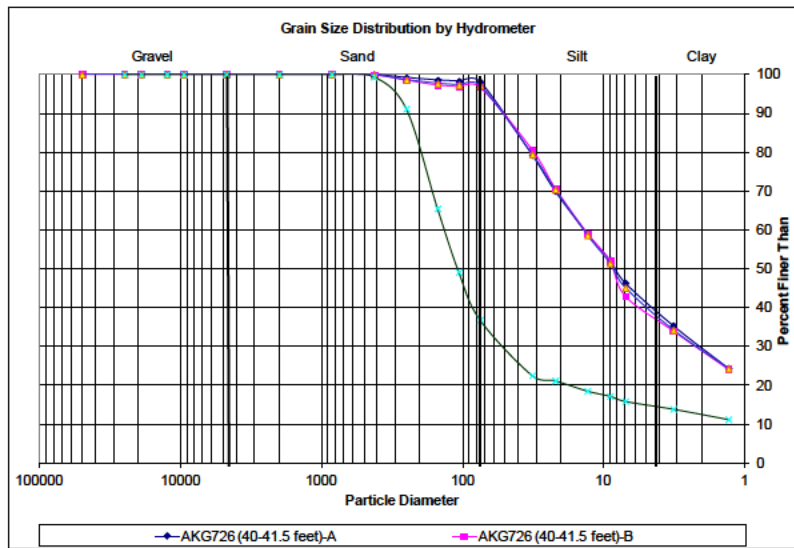
Sample ID	4750	2000	850	425	250	150	106	75	32	22	13	9	7	3.2	1.3
184092A	100.0	100.0	100.0	99.9	99.2	98.5	98.2	98.1	79.3	70.0	59.0	52.3	46.4	35.4	24.5
184092B	100.0	100.0	100.0	99.9	98.5	97.3	96.9	96.7	80.6	70.8	59.1	52.0	43.0	34.0	24.2
184092C	100.0	100.0	100.0	99.8	98.6	97.7	97.3	97.1	79.4	70.4	58.7	51.5	45.1	34.3	24.4
AVE	100.00	100.00	100.00	99.87	98.76	97.82	97.49	97.29	79.77	70.39	58.94	51.89	44.84	34.58	24.34
STDEV	0.00	0.00	0.00	0.07	0.35	0.63	0.68	0.70	0.74	0.39	0.23	0.41	1.71	0.73	0.14
%RSD	0.00	0.00	0.00	0.07	0.35	0.65	0.70	0.72	0.92	0.56	0.39	0.80	3.81	2.11	0.56

This Triplicate applies to the Batch Containing the Following Samples

Sample ID	Date Sampled	Date Set up	Date Started	Date Complete	Data Qualifiers
184080	NA	5/13/05	5/19/05	5/23/05	
184081	NA	5/13/05	5/19/05	5/23/05	
184082	NA	5/13/05	5/19/05	5/23/05	
184083	NA	5/16/05	5/19/05	5/23/05	
184084	NA	5/13/05	5/19/05	5/23/05	
184085	NA	5/16/05	5/19/05	5/23/05	
184086	NA	5/13/05	5/19/05	5/23/05	
184087	NA	5/13/05	5/19/05	5/23/05	
184088	NA	5/13/05	5/19/05	5/23/05	
184089	NA	5/13/05	5/19/05	5/23/05	
184090	NA	5/13/05	5/19/05	5/23/05	
184091	NA	5/13/05	5/19/05	5/23/05	
184092A	NA	5/16/05	5/19/05	5/23/05	
184092B	NA	5/17/05	5/19/05	5/23/05	
184092C	NA	5/17/05	5/19/05	5/23/05	
184093	NA	5/16/05	5/19/05	5/23/05	
184094	NA	5/13/05	5/19/05	5/23/05	

(Nooksack 2/Report/Final report 2010/grain size lab data.pdf)





(Nooksack 2—older/Report/Final Report 2010/Grain size lab results—Wel tag labels_02_04_13.xls)

Appendix Q. Data and Spreadsheet Results for Bradbury and Rothschild (1985) Method Using Specific Capacity for Monitoring Wells on April 4, 2006.

Field Data				Estimated Parameters							Calculated Results						
Location	Well Diam.	Dep h to Water		Test Duration	Mean Pumping Rate	Screened Interval		Storage Coeff. (S)	Well loss Coeff. (C)	Aquifer Thickness (b)	Measured Drawdown (s _m)	Saturated Screen Length (L)	Well loss (s _w)	Partial Penetration Parameter (s _p)	Specific Capacity	Transmissivity (T)	Conductivity (K)
		Initial	Final			Depth to Top	Depth to Bottom										
	inches	feet	feet	hours	gpm	feet	feet	-	sec ² /ft ⁵	feet	feet	feet	feet	-	gpm/ft	sq ft/sec	ft/sec
AKG726	2	8.77	8.98	0.4	1.0	28.0	38.0	0.20	0	35	0.21	10.0	0.0E+00	10.93	4.76	2.8E-02	7.95E-04
AKG726	2	8.77	8.98	0.4	1.0	28.0	38.0	0.25	0	35	0.21	10.0	0.0E+00	10.93	4.76	2.8E-02	7.90E-04
AKG725	2	8.72	8.78	0.25	0.11	6.0	13.0	0.20	0	35	0.06	4.3	0.0E+00	27.49	1.83	2.1E-02	6.07E-04
AKG725	2	8.72	8.78	0.25	0.11	6.0	13.0	0.25	0	35	0.06	4.3	0.0E+00	27.49	1.83	2.1E-02	6.05E-04
AKG723	2	7.98	8.06	0.25	0.11	5.7	12.7	0.20	0	35	0.08	4.7	0.0E+00	24.95	1.38	1.5E-02	4.17E-04
AKG723	2	7.98	8.06	0.25	0.11	5.7	12.7	0.25	0	35	0.08	4.7	0.0E+00	24.95	1.38	1.5E-02	4.16E-04

(My Doc's\Data\Nooksack 2/Report/Final Report 2010/Bradbury-Rothschild-03_28_13.xls—nooksack tab).

See Appendix I for equations used in the spreadsheet.

Appendix R. Water level data.

Table R. 1. Water table elevations in feet assuming the elevation of the top of casing at AKG721 is 134.00 feet (NAVD88).

Date	Well ID						
	AKG721	AKG722	AKG723	AKG724	AKG725	AKG726	AKG727
8/26/2004	123.27	122.44	121.11				
8/27/2004				120.72	122.15	122.07	122.25
9/20/2004		122.60			122.20	122.11	123.30
9/21/2004	123.19		121.37	121.32			
10/18/2004	123.58	123.17		122.5			123.75
10/19/2004			122.10		122.74	122.63	
11/22/2004	126.88	126.45		124.95			127.07
11/23/2004			124.94		125.77	125.71	
12/28/2004	130.48	129.10	127.27	126.78	128.74	128.63	130.12
2/1/2005	130.38	128.61	126.49	127.17	128.19	128.11	129.79
3/2/2005	126.59	125.75	124.12	124.04	125.32	125.22	126.45
3/30/2005	129.05	128.39	125.91	126.17			127.89
3/31/2005					126.98	126.94	
4/25/2005	127.49	126.53		124.43			127.29
4/26/2005			124.76		125.96	125.90	
5/25/2005	125.36	124.54		122.81			125.34
5/26/2005			122.87		124.03	123.95	
7/6/2005	124.44	123.63					124.41
7/7/2005			122.11	122.10	123.12	123.03	
8/16/2005	123.72		121.58	121.41			123.75
8/17/2005		122.96			122.56	122.44	
9/22/2005	123.43				122.27	122.17	
9/21/2005		122.68	121.37	121.26			123.39
10/19/2005	123.45	122.82		121.85			123.48
10/20/2005			121.61		122.37	122.28	
11/17/2005		124.73	123.75	123.69			
11/16/2005	125.26				124.32	124.21	125.31
12/14/2005	125.55	124.55		122.94			125.36
12/15/2005			123.15		124.15	124.08	
1/10/2006	132.75						
1/11/2006		NA	129.64	128.43	127.2	127.11	NA
2/7/2006	131.26	129.29	127.66	126.83			130.35
2/8/2006					129.02	128.86	
3/7/2006	126.07	124.95	123.43	123.06			123.80
3/8/2006					124.69	124.58	
4/4/2006	125.37	124.34	122.86	122.64			125.16
4/5/2006					124.01	123.95	
5/17/2006		123.70	NA	122.08			124.50
5/18/2006	124.64				123.35	123.23	
6/26/2006	123.94	123.09		121.61			123.86
6/27/2006			121.71		122.69	122.57	
8/2/2006	123.37	122.59		121.02	122.22		123.32

Date	Well ID						
	AKG721	AKG722	AKG723	AKG724	AKG725	AKG726	AKG727
8/3/2006			121.19			122.09	
9/13/2006	122.92	122.11			121.78		122.78
9/14/2006			120.84	120.61		121.67	
10/18/2006	122.63	121.79			121.52		122.48
10/19/2006			120.71	120.47		121.43	
11/14/2006	124.17	123.26	122.79	123.06			124.14
11/15/2006					123.19	123.11	
12/12/2006	129.75	128.35	126.93	126.47			129.49
12/13/2006					128.84	128.66	
1/17/2007	128.77	126.77		124.42			127.93
1/18/2007			125.09		126.49	126.35	
2/12/2007	126.86	125.62	124.21	123.66			126.48
2/13/2007					125.37	125.23	
3/28/2007	131.52	129.16	128.22	126.88			130.12
3/29/2007					129.49	129.29	
5/14/2007	125.62		122.98	122.56	124.19	NA	125.30
5/15/2007		124.37					
6/13/2007	124.73	123.59					124.46
6/14/2007			122.23	121.92	123.33	123.21	
7/30/2007	123.78	122.74	121.51	121.24	122.52	122.39	123.52
9/2/2007	123.23	122.31	121.10	120.88	122.04	121.92	123.04
10/1/2007	122.95	122.12	121.02	120.91			122.75
10/2/2007					121.89	121.77	
10/30/2007	124.12	123.41		122.34	123.11		124.02
10/31/2007			122.53			123.01	
11/27/2007	124.97	123.99	122.94	123.12			124.68
11/28/2007					123.77	123.65	
1/3/2008	129.82	127.78		125.44			128.97
1/4/2008			125.99		127.56	127.44	
1/30/2008	126.99	125.78	124.38	123.76			126.53
1/31/2008					125.69	125.54	
2/27/2008	126.58	125.37	124.00	123.42			126.16
2/28/2008					125.18	125.03	
4/1/2008	126.67	125.38		123.64			126.28
4/2/2008			123.95		125.09	124.98	
5/6/2008	125.23	124.00	NA	122.30		123.61	124.88
5/7/2008					123.77	9.07	
6/18/2008	124.80	123.80		122.23	123.46		124.57
6/19/2008			122.48			123.33	
7/22/2008	124.24	123.28	121.91			122.85	124.10
7/23/2008				121.51	122.96	9.83	
9/8/2008	124.07	123.14	121.9	121.63		NA	123.88
9/9/2008					122.85		
10/7/2008	123.61	122.68	121.46	121.25			123.41
10/8/2008					122.40	122.25	
11/12/2008	126.49	127.71				NA	128.21
11/13/2008			126.65	126.49	126.92		

Date	Well ID						
	AKG721	AKG722	AKG723	AKG724	AKG725	AKG726	AKG727
12/9/2008	127.93	126.55	125.08		126.26		127.49
12/10/2008				124.92		126.13	
3/18/2009	126.37	125.29	123.96	124.04	124.99	124.87	126.29

(My Doc's\Data\Nooksack 2-older files\Report\final report\well depths3-reivised datum—Jan_11_charts updated 02_01_13.xls-Appendix-WT elevations tab)

Table R.2. Depth-to-water measurements from the top of the casing in feet.

Date	Well ID						
	AKG721	AKG722	AKG723	AKG724	AKG725	AKG726	AKG727
8/26/2004	10.73	8.36	9.73				
8/27/2004				8.25	10.58	10.61	9.18
9/20/2004		8.20			10.53	10.57	8.13
9/21/2004	10.81		9.47	7.65			
10/18/2004	10.42	7.63		6.47			7.68
10/19/2004			8.74		9.99	10.05	
11/22/2004	7.12	4.35		4.02			4.36
11/23/2004			5.90		6.96	6.97	
12/28/2004	3.52	1.70	3.57	2.19	3.99	4.05	1.31
2/1/2005	3.62	2.19	4.35	1.80	4.54	4.57	1.64
3/2/2005	7.41	5.05	6.72	4.93	7.41	7.46	4.98
3/30/2005	4.95	2.41	4.93	2.80			3.54
3/31/2005					5.75	5.74	
4/25/2005	6.51	4.27		4.54			4.14
4/26/2005			6.08		6.77	6.78	
5/25/2005	8.64	6.26	7.97	6.16			6.09
5/26/2005			7.97		8.70	8.73	
7/6/2005	9.56	7.17					7.02
7/7/2005			8.73	6.87	9.61	9.65	
8/16/2005	10.28		9.26	7.56			7.68
8/17/2005		7.84			10.17	10.24	
9/22/2005	10.57				10.46	10.51	
9/21/2005		8.12	9.47	7.71			8.04
10/19/2005	10.55	7.98		7.12			7.95
10/20/2005			9.23		10.36	10.40	
11/17/2005		6.07	7.09	5.28			
11/16/2005	8.74				8.41	8.47	6.12
12/14/2005	8.45	6.25		6.03			6.07
12/15/2005			7.69		8.58	8.60	
1/10/2006	1.25		1.20	0.51			
1/11/2006			1.25	0.54	1.77	1.86	NA
2/7/2006	2.74	1.51	3.18	2.14			1.08
2/8/2006					3.71	3.82	
3/7/2006	7.93	5.85	7.41	5.91			7.63
3/8/2006					8.04	8.10	
4/4/2006	8.63	6.46	7.98	6.33			6.27
4/5/2006					8.72	8.73	
5/17/2006		7.10	NA	6.89			6.93
5/18/2006	9.36				9.38	9.45	
6/26/2006	10.06	7.71		7.36			7.57
6/27/2006			9.13		10.04	10.11	
8/2/2006	10.63	8.21		7.95	10.51		8.11
8/3/2006			9.65			10.59	
9/13/2006	11.08	8.69			10.95		8.65
9/14/2006			10.00	8.36		11.01	
10/18/2006	11.37	9.01			11.21		8.95

Date	Well ID						
	AKG721	AKG722	AKG723	AKG724	AKG725	AKG726	AKG727
10/19/2006			10.13	8.50		11.25	
11/14/2006	9.83	7.54	8.05	5.91			7.29
11/15/2006					9.54	9.57	
12/12/2006	4.25	2.45	3.91	2.50			1.94
12/13/2006					3.89	4.02	
1/17/2007	5.23	4.03		4.55			3.50
1/18/2007			5.75		6.24	6.33	
2/12/2007	7.14	5.18	6.63	5.31			4.95
2/13/2007					7.36	7.45	
3/28/2007	2.48	1.64	2.62	2.09			1.31
3/29/2007					3.24	3.39	
5/14/2007	8.38		7.86	6.41	8.54	NA	6.13
5/15/2007		6.43					
6/13/2007	9.27	7.21					6.97
6/14/2007			8.61	7.05	9.40	9.47	
7/30/2007	10.22	8.06	9.33	7.73	10.21	10.29	7.91
9/2/2007	10.77	8.49	9.74	8.09	10.69	10.76	8.39
10/1/2007	11.05	8.68	9.82	8.06			8.68
10/2/2007					10.84	10.91	
10/30/2007	9.88	7.39		6.63	9.62		7.41
10/31/2007			8.31			9.67	
11/27/2007	9.03	6.81	7.90	5.85			6.75
11/28/2007					8.96	9.03	
1/3/2008	4.18	3.02		3.53			2.46
1/4/2008			4.85		5.17	5.24	
1/30/2008	7.01	5.02	6.46	5.21			4.90
1/31/2008					7.04	7.14	
2/27/2008	7.42	5.43	6.84	5.55			5.27
2/28/2008					7.55	7.65	
4/1/2008	7.33	5.42		5.33			5.15
4/2/2008			6.89		7.64	7.70	
5/6/2008	8.77	6.80	NA	6.67			6.55
5/7/2008					8.96	9.07	
6/18/2008	9.20	7.00		6.74	9.27		6.86
6/19/2008			8.36			9.35	
7/22/2008	9.76	7.52	8.93				7.33
7/23/2008				7.46	9.77	9.83	
9/8/2008	9.93	7.66	8.94	7.34			7.55
9/9/2008					9.88		
10/7/2008	10.39	8.12	9.38	7.72			8.02
10/8/2008					10.33	10.43	
11/12/2008	7.51	3.09					3.22
11/13/2008			4.19	2.48	5.81		
12/9/2008	6.07	4.25	5.76		6.47		3.94
12/10/2008				4.05		6.55	
3/18/2009	7.63	5.51	6.88	4.93			5.14
3/19/2009					7.74	7.81	

(Well depth3-revised datum—Jan_11_charts updated 02_01_13.xls-Appendix-depth to H20 tab)

Appendix S. Groundwater Quality Results

Table S.1. Groundwater quality results from monitoring wells.

Field Measurements						
Well Tag Number	Sample Date	Depth to Groundwater (ft below top of casing)	Temp-erature (C0)	pH (Standard Units)	Dissolved Oxygen (mg/L)	Conductivity (umhos/cm)
AKG-721	8/27/04	10.73				
AKG-721	9/21/04	10.81	12.7	5.61	9.40	302
AKG-721	10/18/04	10.42	12.5	--	7.80	250
AKG-721	11/22/04	7.12	12.1	5.70	7.02	338
AKG-721	12/28/04	3.52	10.7	5.78	8.80 P	334
AKG-721	2/1/05	3.62	9.7	5.69	10.3	368
AKG-721	3/2/05	7.41	9.4	5.61	8.08	386
AKG-721	3/30/05	4.95	10.4	5.72	8.80	367
AKG-721	4/25/05	6.51	10.5	5.70	9.18	338
AKG-721	5/25/05	8.64	11.0	5.67	8.30	350
AKG-721	7/6/05	9.56	11.6	5.61	7.02	367
AKG-721	8/16/05	10.28	12.6	5.77	7.81	359
AKG-721	9/21/05	10.57	12.1	5.48	6.85	370
AKG-721	10/19/05	10.55	12.2	5.73	6.87	418
AKG-721	11/17/05	8.74	12.5	5.63	5.60	372
AKG-721	12/14/05	8.45	11.0	5.59	6.98	307
AKG-721	1/10/06	1.25	--	5.86	--	--
AKG-721	2/7/06	2.74	9.5	5.79	6.56	252
AKG-721	3/7/06	7.93	9.2	5.67	8.90	264
AKG-721	4/4/06	8.63	10.3	5.84	8.00	245
AKG-721	5/17/06	9.36	10.2	5.76	8.85	260
AKG-721	6/26/06	10.06	11.5	5.78	7.68	250
AKG-721	8/2/06	10.63	11.9	5.61	7.60 P	264

Laboratory Analyses ¹													
Ammonia-N (mg/L)		Nitrite+ Nitrate-N (mg/L)		Total Persulfate N (mg/L)		Ortho Phosphorus (mg/L)		Total Phosphorus (mg/L)		Chloride (mg/L)	Total Dissolved Solids (mg/L)		Organic Carbon (mg/L)
0.010	U	17.7		18.4		0.0047		0.0023	P	12.9	224	J	1 1
0.017		14.5		14.0		0.0050		0.0020	UP	10.5	196		1.0 U
0.010	U	22.6		23.5		0.0045		0.0025		16.6	217		1 5
0.010	U	21.2		20.9		0.0080		0.0038		14.4	210	J	1.4
0.010	U	24.2		22.4		0.0070		0.0054		15.5	251		1 9
0.010	U	25.8		25.3		0.0066		0.0045		19.1	268		1 3
0.010	U	24.7		23.8		0.0076		0.0061	P	17.4	252		7 1
0.010	U	22.6		19.8		--		0.0061	P	14.8	245		1 3
0.010	U	21.7		22.9		--		0.0061	P	16.0	275		3 3J
0.010	U	24.1		23.3		--		0.0067		16.7	277		2 3
0.010	U	25.3		24.6		--		0.0033		15.6	268		1 9
0.010	U	27.1		25.8		--		0.0038	P	16.0	262		1.4
0.010	U	28.3		27.0		--		0.0040	P	19.1	284		2 3
0.010	U	24.9		26.1		--		0.0041		17.0	264		1 2
0.010	U	16.9		15.9		--		0.0065		11.0	229		1 5
0.010	U	11.5		10.9		--		0.0078		7.97	194		2 1
0.010	U	12.4		12.0		--		0.0095		7.63	187	P	2 1
0.010	U	12.7		12.3		--		0.0097		8.10	187		1.7
0.010	U	13.8		11.9		--		0.0050	U	7.84	172		1.6
0.012	UJ	11.4		11.2		--		0.0050	U	8.28	187		1 2
0.010	U	10.7		10.6		--		0.0075		8.59	195		1 5
0.010	U	10.9		12.7		--		0.0047		10.4	197		1 5

Field Measurements						
Well Tag Number	Sample Date	Depth to Groundwater (ft below top of casing)	Temperature (C0)	pH (Standard Units)	Dissolved Oxygen (mg/L)	Conductivity (umhos/cm)
AKG-721	9/13/06	11.08	11.8	5.69	10.54 P	252
AKG-721	10/18/06	11.37	12.1	5.80	6.85	244
AKG-721	11/14/06	9.83	11.6	5.88	7.30	243
AKG-721	12/12/06	4.25	11.0	5.82	7.95 P	249
AKG-721	1/17/07	5.23	8.9	5.80	10.01 P	257
AKG-721	2/12/07	7.14	9.0	5.91	8.29 P	240
AKG-721	3/28/07	2.48	8.4	5.98	8.43 P	228
AKG-721	5/14/07	8.38	10.8	5.87	9.47	221
AKG-721	6/13/07	9.27	10.5	5.90	8.56	232
AKG-721	7/30/07	10.22	11.8	5.92	7.23 P	244
AKG-721	9/2/07	10.77	12.0	5.75	8.24	250
AKG-721	10/1/07	11.05	11.9	5.75	7.05	268
AKG-721	10/30/07	9.88	12.0	5.76	7.94	260
AKG-721	11/27/07	9.03	11.1	5.89	8.31	250
AKG-721	1/3/08	4.18	9.1	5.92	8.51	220
AKG-721	1/30/08	7.01	8.0	5.86	10.0	229
AKG-721	2/27/08	7.42	8.6	5.87	8.10	214
AKG-721	4/1/08	7.33	8.6	5.91	8.08	207
AKG-721	5/6/08	8.77	9.0	5.96	8.55	207
AKG-721	6/18/08	9.20	10.1	5.82	--	221
AKG-721	7/22/08	9.76	11.9	5.75	8.03	226
AKG-721	8/26/08	10.18	12.1	5.82	--	210
AKG-721	9/8/08	9.93	12.9	5.84	6.49	216
AKG-721	10/7/08	10.39	12.0	5.86	6.31 P	213
AKG-721	11/12/08	7.51	11.6	5.87	7.10 P	204
AKG-721	12/9/08	6.07	10.4	5.90	8.61 P	225
AKG-721	3/18/09	7.63	8.3	5.83	6.75	233

Laboratory Analyses ¹												
Ammonia-N (mg/L)		Nitrite+ Nitrate-N (mg/L)		Total Persulfate N (mg/L)		Ortho Phosphorus (mg/L)		Total Phosphorus (mg/L)		Chloride (mg/L)	Total Dissolved Solids (mg/L)	Organic Carbon (mg/L)
0.010	U	12.2		12.6		--		0.0049		9.18	222	1.4
0.010	U	12.6		11.7		--		0.0045		7.87	169	3 3
0.010	U	10.7	P	11.1	P	--		0.0063	P	7.52	154	2.3/3.2JP
0.010	U	12.3		11.1		--		0.0079	P	8.98 P	185	1.4 P
0.010	U	11.8		12.2		--		--		7.59	174	1.8
0.010	U	9.92		9.90		--		--		7.09	160	1.6
0.010	U	7.78		7.65		--		--		4.22	156	2.0
0.010	U	7.37		7.29		--		--		5.73	143	1.6
0.010	U	7.53		7.97	P	--		--		6.68	157	1 5
0.010	U	10.2		10.7		--		--		9.14	171	1 5
0.010	U	12.1	P	12.0		--		--		9.89	181	1 5
0.010	U	12.8		13.5		--		--		10.2	200	1 5
0.010	U	11.6		11.5		--		--		9.11	178	1.4
0.010	U	10.2		10.3		--		--		6.04	158	1.6
0.010	U	7.51		8.13		--		--		4.93 P	146	1 9
0.010	U	8.01		9.08		--		--		5.79	153	1.7
0.010	U	6.66		6.93		--		--		4.66	154	1 9
0.010	U	5.53	P	5.53		--		--		4.29	138	1.7
0.010	U	6.30		6.51		--		--		5.17	152	1.6
0.010	U	7.51		7.99		--		--		6.05	154	1.6
0.010	U	7.35		7.61		--		--		6.18	147	1.6
0.010	U	8.02		8.41		--		--		6.54	156	1.6
0.010	U	7.82		7.37		--		--		6.39 J	135	1 5
0.010	U	6.44		7.07		--		--		6.67	144	1 5
0.010	U	5.42		5.94		--		--		6.22	136	1 5
0.010	U	7.37		7.54		--		--		6.53	153	1 9
0.010	U	8.13		8.17		--		--		6.70	156	1.6

Field Measurements						
Well Tag Number	Sample Date	Depth to Groundwater (ft below top of casing)	Temperature (C0)	pH (Standard Units)	Dissolved Oxygen (mg/L)	Conductivity (umhos/cm)
AKG-722	8/27/04	8.36				
AKG-722	9/21/04	8.20	13.1	5.50	0.10	334
AKG-722	10/18/04	7.63	12.6	--	0.36	324
AKG-722	11/22/04	4.35	11.6	5.47	6.35	397
AKG-722	12/28/04	1.70	9.6	5.51	8.30 P	599
AKG-722	2/1/05	2.19	7.7	5.50	7.50	402
AKG-722	3/2/05	5.05	8.2	5.35	8.61	248
AKG-722	3/30/05	2.41	8.6	5.63	4.58	382
AKG-722	4/25/05	4.27	10.5	5.70	9.18	338
AKG-722	5/25/05	6.26	10.8	5.49	5.40	265
AKG-722	7/6/05	7.17	12.0	5.43	2.64	278
AKG-722	8/16/05	7.84	12.4	5.46	2.58	300
AKG-722	9/21/05	8.12	12.8	5.36	1.90	316
AKG-722	10/19/05	7.98	12.3	5.63	1.13	357
AKG-722	11/16/05	6.07	11.4	5.56	0.85	352
AKG-722	12/14/05	6.25	10.1	5.39	5.51	254
AKG-722	1/10/06		--2	--2	--2	--2
AKG-722	2/7/06	1.51	8.1	5.80	6.10	156**
AKG-722	3/7/06	5.85	7.9	5.56	6.28	228
AKG-722	4/4/06	6.46	10.1	5.58	8.34	226
AKG-722	5/17/06	7.10	10.5	5.32	8.10	240
AKG-722	6/26/06	7.71	12.4	5.50	6.66	169
AKG-722	8/2/06	8.21	12.9	5.48	5.24 P	275
AKG-722	9/13/06	8.69	12.1	5.50	1.34 P	271
AKG-722	10/18/06	9.01	12.2	5.62	0.51	282
AKG-722	11/14/06	7.54	10.9	5.65	0.25	312

Laboratory Analyses ¹													
Ammonia-N (mg/L)		Nitrite+ Nitrate-N (mg/L)		Total Persulfate N (mg/L)		Ortho Phosphorus (mg/L)		Total Phosphorus (mg/L)		Chloride (mg/L)	Total Dissolved Solids (mg/L)		Organic Carbon (mg/L)
0.010	U	5.60		5.45		0.0066		0.0076	P	15.7	214		2.6
0.014		3.49		4.21		0.0054		0.0023	P	15.2	220	J	2.5
0.010	U	20.6		22.3		0.0033		0.0034		16.6	250		3.2
0.010	U	45.3		43.7		0.0043		0.0032		30.6	381	J	4.9
0.010	U	23.6		22.3		0.0030	U	0.0037		16.9	274		6.0
0.010	U	13.1		13.5		0.0034		0.0037		9.06	183		5.6
0.010	U	26.3		26.7		0.0037		0.0037	P	18.4	261		3.7
0.010	U	22.6		19.8		--		0.0061	P	14.8	245		1.3
0.024		12.7		14.7		--		0.0028		9.57	188		7.1
0.010	U	11.9		10.9		--		0.0038		11.0	200		4.9
0.010	U	10.7		11.9		--		0.0030		12.3	207		3.7
0.010	U	9.18		12.6		--		0.0038		14.3	210		3.1
0.010	U	9.89		9.45		--		0.0033		16.7	227		3.0
0.010	U	9.20		9.09		--		0.0037		15.5	227		2.9
0.010	U	11.7		10.9		--		0.0038		9.28	193		5.8
--2		--2		--2		--2		--2		--2	--2		--2
0.010	U	10.8		10.7		--		0.0057		10.6	172	P	8.2
0.010	U	11.3		10.3		--		0.0056		10.3	171		7.3
0.010	U	9.94		11		--		0.0050	U	10.9	157		7.1
0.010	U	9.62		9.93		--		0.0050	U	11.2	173		5.1
0.010	U	9.88		10		--		0.0050	U	13.5	178		3.9
0.010	U	7.44		8.9		--		0.0033		12.4	197		3.4
0.010	U	5.80		5.94		--		0.0040		12.3	190		3.0
0.010	U	4.59		4.67		--		0.0033		12.7	193		4.7
0.010	U	1.82	P	1.54	P	--		0.0050	P	13.1	201		3.6

Field Measurements						
Well Tag Number	Sample Date	Depth to Groundwater (ft below top of casing)	Temperature (C0)	pH (Standard Units)	Dissolved Oxygen (mg/L)	Conductivity (umhos/cm)
AKG-722	12/12/06	2.45	9.8	5.84	7.77 P	373
AKG-722	1/17/07	4.03	7.1	5.84	10.74 P	328
AKG-722	2/12/07	5.18	7.3	5.76	9.66 P	291
AKG-722	3/28/07	1.64	8.4	5.91	8.64 P	231
AKG-722	5/14/07	6.43	9.9	5.85	8.31	192
AKG-722	6/13/07	7.21	10.3	5.77	6.86	210
AKG-722	7/30/07	8.06	12.1	5.73	3.90 P	216
AKG-722	9/2/07	8.49	12.4	5.57	2.65	208
AKG-722	10/1/07	8.68	12.5	5.56	0.75	231
AKG-722	10/30/07	7.39	11.9	5.56	0.37	285
AKG-722	11/27/07	6.81	10.8	5.74	4.23	216
AKG-722	1/3/08	3.02	7.5	5.90	9.06	246
AKG-722	1/30/08	5.02	8.1	5.86	9.30	226
AKG-722	2/27/08	5.43	6.8	5.83	7.46	254
AKG-722	4/1/08	5.42	8.6	5.91	8.08	207
AKG-722	5/6/08	6.8	8.7	5.80	8.07	225
AKG-722	6/18/08	7.00	10.4	5.69	5.03	223
AKG-722	7/22/08	7.52	12.3	5.63	4.48	227
AKG-722	8/26/08	7.98	13.2	5.46	2.10	217
AKG-722	9/8/08	7.66	13.6	5.65	1.70	212
AKG-722	10/7/08	8.12	12.6	5.53	1.58 P	212
AKG-722	11/12/08	3.09	11.3	5.66	0.45 P	221
AKG-722	12/9/08	4.25	8.9	5.86	7.40 P	339
AKG-722	3/18/09	5.51	7.7	5.70	3.45	267
AKG-723	8/27/04	9.73				
AKG-723	9/21/04	9.47	13.2	5.16	1.50	511

Laboratory Analyses ¹															
Ammonia-N (mg/L)		Nitrite+ Nitrate-N (mg/L)		Total Persulfate N (mg/L)		Ortho Phosphorus (mg/L)		Total Phosphorus (mg/L)		Chloride (mg/L)		Total Dissolved Solids (mg/L)		Organic Carbon (mg/L)	
0.010	U	17.6		17.7		--		0.0053	P	8.89	P	246		6.2	P
0.010	U	19.4		20.2		--		--		15.6		232		8.0	
0.010	U	15.9		16.6		--		--		15.2	P	161	P	7.4	
0.010	U	9.32		8.86		--		--		6.23		164		8.8	
0.010	U	3.71		4.26	P	--		--		5.82		133		8.4	
0.033		5.00		6.46		--		--		6.54		147		7.8	
0.010	U	6.79		6.13		--		--		6.19		184		5.3	
0.010	U	3.94	P	4.18		--		--		6.24		149		4.8	
0.010	U	4.71		4.66		--		--		7.38		167		4.2	
0.010	U	3.97		4.15		--		--		8.51		187		3.9	
0.010	U	3.96		4.48		--		--		6.53		151		6.6	
0.010	U	10.5		11.3		--		--		7.13		164		9.1	
0.010	U	8.03		9.34		--		--		7.59	P	149		1.6	
0.010	U	9.72		11.5		--		--		4.84		186		9.6	
0.010	U	5.53	P	5.53		--		--		4.29		138		1.7	
0.010	U	8.63		9.63		--		--		4.63		165		7.5	
0.010	U	8.10		8.92		--		--		4.40		163		7.6	
0.010	U	7.68		7.83		--		--		4.70		157		5.8	
0.010	U	5.97		6.53		--		--		4.66		156		5.0	
0.010	U	5.67		5.88		--		--		4.78	J	140		5.1	
0.010	U	3.58		4.19		--		--		4.83		149		5.1	
0.010	U	1.90		2.21		--		--		4.98		147		4.1	
0.010	U	15.3		15.9		--		--		11.7		217		8.2	
0.010	U	9.12		9.28		--		--		6.28		182		4.5	
0.010	U	22.2		22.2		0.007		0.0052	P	23.0		350	J	1.6	

Field Measurements						
Well Tag Number	Sample Date	Depth to Groundwater (ft below top of casing)	Temperature (C0)	pH (Standard Units)	Dissolved Oxygen (mg/L)	Conductivity (umhos/cm)
AKG-723	10/18/04	8.74	12.4	--	0.77	507
AKG-723	11/22/04	5.90	12.0	5.26	1.09	474
AKG-723	12/28/04	3.57	10.1	5.28	3.30 P	517
AKG-723	2/1/05	4.35	8.7	5.16	3.70	565
AKG-723	3/2/05	6.72	8.6	5.09	3.41	556
AKG-723	3/30/05	4.93	8.9	5.46	6.49	462
AKG-723	4/26/05	6.08	9.2	5.20	1.35	387
AKG-723	5/26/05	7.97	10.1	5.24	3.49	389
AKG-723	7/6/05	8.73	11.0	5.22	3.36	426
AKG-723	8/16/05	9.26	12.2	5.22	2.83	441
AKG-723	9/21/05	9.47	13.3	5.13	1.87	446
AKG-723	10/20/05	9.23	12.2	5.32	2.12	438
AKG-723	11/16/05	7.09	11.7	5.28	2.35	402
AKG-723	12/15/05	7.69	11.3	5.19	2.05	398
AKG-723	1/11/06	1.25	8.5	5.50	4.45	338
AKG-723	2/7/06	3.18	8.4	5.30	3.33	322
AKG-723	3/7/06	7.41	8.9	5.25	2.91	311
AKG-723	4/4/06	7.98	9.7	5.36	4.49	332
AKG-723	5/17/06	--3	--3	--3	--3	--3
AKG-723	6/26/06	9.13	11.2	5.23	4.42	313
AKG-723	8/3/06	9.65	11.7	5.19	7.07 P	333
AKG-723	9/14/06	10.00	11.8	5.30	1.14 P	334
AKG-723	10/18/06	10.13	12.0	5.38	0.16	332
AKG-723	11/14/06	8.05	11.1	5.38	0.56	367
AKG-723	12/12/06	3.91	9.5	5.35	4.44 P	377
AKG-723	1/17/07	5.75	8.1	5.39	0.50 P	335
AKG-723	2/12/07	6.63	8.0	5.38	1.74 P	355

Laboratory Analyses ¹													
Ammonia-N (mg/L)		Nitrite+ Nitrate-N (mg/L)		Total Persulfate N (mg/L)		Ortho Phosphorus (mg/L)		Total Phosphorus (mg/L)		Chloride (mg/L)	Total Dissolved Solids (mg/L)		Organic Carbon (mg/L)
0.012		23.2		25.5		0.006		0.0020	UP	25.4	343		1 5
0.015		30.6		33.4		0.0047		0.0043		23.3	326		2.8
0.010	U	33.7		35.8		0.0076		0.0053		19.5	351	J	2 9
0.010	U	39.0		36.7		0.005		0.0043		21.0	392		2 5
0.010	U	39.5		39.1		0.0051		0.0037		22.2	358		2 3
0.010	U	34.6		35.1		0.0051		0.0031	P	20.3	313		1.8
0.015		27.7		27.0		--		0.0047	P	15.4	309		3 3
0.010		20.4		21.9		--		0.0034		15.9	298		6.7J
0.010	U	29.4		27.9		--		0.0031		17.9	323		1.7
0.010	U	28.5		29.6		--		0.0032		20.0	336		1 3
0.010	U	27.1		27.1		--		0.0037		19.9	320		1.7
0.010	U	25.6		24.9		--		0.0036		18.6	316		1.7
0.010	U	25.6		24.7		--		0.0042		15.4	279		2 5
0.010	U	21.1		21.3		--		0.0048		16.4	280		2 3
0.010	U	18.5		18.2		--		0.0071		12.9	267		4 2
0.010	U	16.4		16.0		--		0.0066		13.0	238	P	3 5
0.010	U	14.7		13.9		--		0.0051		13.0	234		2.8
0.010	U	17.5		16.3		--		0.0050	U	13.1	240		2.0
--3		--3		--3		--3		--3		--3	--3		--3
0.010	U	14.6		13.6		--		0.0082		12.2	230		1 9
0.010	U	11.4		12.6		--		0.0020	U	14.1	214		1 9
0.010	U	11.9		12.2		--		0.0046		14.6	234		1 9
0.010	U	8.93		11.2		--		0.0041		14.6	237		2.8
0.010	U	5.30	P	5.81	P	--		0.0063	P	15.0	238		3 3 P
0.010	U	17.0		16.7		--		0.0076	P	18.6 P	258		3 2 P
0.010	U	20.1		19.8		--		--		13.8	247		4.4
0.010	U	19.6		20.4		--		--		11.1 P	203	P	3 2

Field Measurements						
Well Tag Number	Sample Date	Depth to Groundwater (ft below top of casing)	Temperature (C0)	pH (Standard Units)	Dissolved Oxygen (mg/L)	Conductivity (umhos/cm)
AKG-723	3/28/07	2.62	7.9	5.57	3.51 P	271
AKG-723	5/14/07	7.86	9.4	5.50	4.49	292
AKG-723	6/13/07	8.61	9.7	5.44	3.51	306
AKG-723	7/30/07	9.33	11.4	5.65	2.42 P	324
AKG-723	9/2/07	9.74	11.8	5.35	1.87	298
AKG-723	10/1/07	9.82	11.8	5.33	1.20	299
AKG-723	10/30/07	8.31	11.5	5.43	2.51	293
AKG-723	11/27/07	7.90	10.5	5.46	1.63	287
AKG-723	1/4/08	4.85	8.6	5.40	2.19	271
AKG-723	1/30/08	6.46	7.8	5.38	1.66	253
AKG-723	2/27/08	6.84	7.4	5.39	2.39	256
AKG-723	4/2/08	6.89	8.2	5.37	0.98	260
AKG-723	5/6/08	--3	--3	--3	--3	--3
AKG-723	6/19/08	8.36	9.8	5.38	2.65	272
AKG-723	7/22/08	8.93	11.4	5.65	1.97	281
AKG-723	9/8/08	8.94	13.5	5.45	1.69	286
AKG-723	10/7/08	9.38	11.9	5.34	2.89 P	266
AKG-723	11/13/08	4.19	11.7	5.36	3.03 P	292
AKG-723	12/9/08	5.76	10.0	5.44	1.88 P	274
AKG-723	3/18/09	6.88	7.8	5.41	4.04	320
AKG-724	8/27/04	8.25				
AKG-724	9/21/04	7.65	13.7	4.69	8.60	408
AKG-724	10/18/04	6.47	12.7	NA	0.00	430
AKG-724	11/22/04	4.02	11.9	5.30	1.30	413
AKG-724	12/28/04	2.19	10.3	4.83	3.90 P	490
AKG-724	2/1/05	1.80	8.5	4.82	3.00	422

Laboratory Analyses ¹													
Ammonia-N (mg/L)		Nitrite+ Nitrate-N (mg/L)		Total Persulfate N (mg/L)		Ortho Phosphorus (mg/L)		Total Phosphorus (mg/L)		Chloride (mg/L)	Total Dissolved Solids (mg/L)		Organic Carbon (mg/L)
0.010	U	14.0		15.1		--		--		13.2	197		1 9
0.010	U	11.9		11.8	P	--		--		7.98	197		2 3
0.010	U	12.8		12.9		--		--		9.21	211		2 2
0.010	U	14.8		14.2		--		--		12.3	244		1.7
0.010	U	15.6	P	12.6		--		--		9.41	209		1 9
0.010	U	12.7		12.2		--		--		8.93	216		1.8
0.010	U	9.50		10.0		--		--		8.02	205		3.4
0.010	U	9.28		9.22		--		--		8.27	201		2.6
0.010	U	9.55		9.99		--		--		6.80	185		3.8
0.010	U	9.80		10.6		--		--		6.34 P	174		4 2
0.010	U	11.0		11.4		--		--		5.91	184		4 2
0.010	U	11.8	P	13.5		--		--		6.23	192		3.8
--3		--3		--3		--3		--3		--3	--3		--3
0.010	U	9.41		9.8		--		--		6.51	193		2 9
0.010	U	8.13		8.37		--		--		6.67	193		2.0
0.010	U	8.51		8.44		--		--		7.01 J	186		2 1
0.010	U	8.00		8.22		--		--		7.16	198		2.0
0.010	U	11.4		12.8		--		--		5.36	206		4.6
0.010	U	9.42		9.85		--		--		6.30	186		4.0
0.010	U	17.9		14.5		--		--		8.73	232		1.8
0.010	U	19.7		19.2		0.0058		0.0060	P	18.6	270	J	1.7
0.010	U	17.2		17.1		0.0049		0.0020	UP	20.8	288		1.6
0.010	U	15.9		15.6		0.0048		0.0036		19.7	268		2 1
0.010	U	26.8		26.9		0.0075		0.0028		19.6	323	J	1 9
0.010	U	27.8		26.8		0.0045		0.0021		14.7	285		1 5

Field Measurements						
Well Tag Number	Sample Date	Depth to Groundwater (ft below top of casing)	Temperature (C0)	pH (Standard Units)	Dissolved Oxygen (mg/L)	Conductivity (umhos/cm)
AKG-724	3/2/05	4.93	8.2	4.84	0.87	324
AKG-724	3/30/05	2.80	9.1	4.96	2.10	326
AKG-724	4/25/05	4.54	9.7	4.93	1.04	323
AKG-724	5/26/05	6.16	10.6	4.93	0.48	342
AKG-724	7/7/05	6.87	11.5	4.77	0.36	385
AKG-724	8/16/05	7.56	13.3	4.74	0.38	374
AKG-724	9/21/05	7.71	13.4	4.63	0.42	381
AKG-724	10/19/05	7.12	12.6	4.94	6.26	337
AKG-724	11/16/05	5.28	11.3	5.06	1.77	401
AKG-724	12/14/05	6.03	10.6	4.67	1.90	426
AKG-724	1/10/06	0.54	11.0	4.87	3.54	353
AKG-724	2/7/06	2.14	8.6	4.92	2.79	312
AKG-724	3/7/06	5.91	8.9	4.82	1.34	310
AKG-724	4/4/06	6.33	9.6	4.92	2.28	283
AKG-724	5/17/06	6.89	10.4	4.80	1.01	273
AKG-724	6/26/06	7.36	12.4	4.87	4.81	276
AKG-724	8/2/06	7.95	12.3	4.79 P	1.11	298
AKG-724	9/14/06	8.36	12.6	4.76 P	0.61	302
AKG-724	10/19/06	8.50	12.4	4.85	0.45	335
AKG-724	11/14/06	5.91	11.1	4.84	1.06	342
AKG-724	12/12/06	2.50	10.4	4.85	4.92 P	299
AKG-724	1/17/07	4.55	8.3	4.99	5.56 P	308
AKG-724	2/12/07	5.31	8.4	4.97	4.02 P	337
AKG-724	3/28/07	2.09	8.6	5.01	4.97 P	299
AKG-724	5/14/07	6.41	10.1	5.01	0.87	270
AKG-724	6/14/07	7.05	10.7	4.98	0.60	279
AKG-724	7/30/07	7.73	12.6	5.20	0.34 P	267

Laboratory Analyses ¹															
Ammonia-N (mg/L)		Nitrite+ Nitrate-N (mg/L)		Total Persulfate N (mg/L)		Ortho Phosphorus (mg/L)		Total Phosphorus (mg/L)		Chloride (mg/L)		Total Dissolved Solids (mg/L)		Organic Carbon (mg/L)	
0.010	U	22.1		20.7		0.0050		0.0020		13.3		246		1	2
0.010	U	18.1		16.0		0.0043		0.0024	P	12.8		218		1	5
0.010	U	15.7		14.9		--		0.0019	P	10.8		219		1	2
0.018		16.5		18.7		--		0.0013		12.6		227		1.8	J
0.010	U	20.3		19.3		--		0.0019		16.4		272		1.7	
0.010	U	18.3		17.2		--		0.0019		17.1		251		1	9
0.010	U	16.8		18.4		--		0.0040		18.9		247		1	9
0.010	U	13.2		12.7		--		0.0021		19.1		258		2.0	
0.010	U	17.2		16.4		--		0.0021		17.7		266		1.8	
0.010	U	19.0		19.5		--		0.0023		17.8		287		1.8	
0.010	U	16.9		18.1		--		0.0023		16.0		233*		2	1
0.010	U	14.0		15.6		--		0.0050	U	14.5		222	P	2	2
0.010	U	13.2		12.8		--		0.0050	U	12.8		219		1.6	
0.010	U	8.41		8.79		--		0.0050	U	12.5		197		1.6	
0.010	U	7.32		9.16		--		0.0050	U	12.0		196		1	5
0.010	U	8.77		8.76		--		0.0050	U	13.9		185		1.7	
0.010	U	13.5		13.4		--		0.0037		14.3		232		1.8	
0.028		13.0		13.2		--		0.0025		14.0		213		2	2
0.010	U	14.4		14.2		--		0.0016		14.8		227		3.6	
0.010	U	13.2	P	16.2	P	--		0.0027	P	14.9		216		4.6	P
0.010	U	9.66		8.81		--		0.0030	P	17.2	P	199		1.7	P
0.010	U	13.9		14.3		--		--		16.2	P	215	P	2	5
0.010	U	15.7		16.0		--		--		16.8		222		4	9
0.010	U	14.2		12.8		--		--		8.34		191		3.7	
0.010	U	11.9		11.9	P	--		--		10.6		179		1.7	
0.010	U	6.81		7.42		--		--		8.95		193		1	9
0.010	U	4.56		5.27		--		--		9.46		208		2	2

Field Measurements						
Well Tag Number	Sample Date	Depth to Groundwater (ft below top of casing)	Temperature (C0)	pH (Standard Units)	Dissolved Oxygen (mg/L)	Conductivity (umhos/cm)
AKG-724	9/2/07	8.09	12.7	4.88	0.36	239
AKG-724	10/1/07	8.06	12.8	4.90	0.34	227
AKG-724	10/30/07	6.63	12.4	4.96	0.88	255
AKG-724	11/27/07	5.85	11.0	4.94	1.38	255
AKG-724	1/3/08	3.53	8.8	4.95	3.87	231
AKG-724	1/30/08	5.21	7.6	4.95	3.49	237
AKG-724	2/27/08	5.55	7.6	4.97	2.71	239
AKG-724	4/1/08	5.33	8.3	5.00	1.64	235
AKG-724	5/6/08	6.67	9.2	5.01	0.67	260
AKG-724	6/18/08	6.74	11.0	4.92	0.65	235
AKG-724	7/23/08	7.46	12.1	4.68	0.09	252
AKG-724	9/8/08	7.34	13.7	4.88	0.41	270
AKG-724	10/7/08	7.72	12.9	4.78	0.50 P	238
AKG-724	11/13/08	2.48	11.5	4.77	1.64 P	248
AKG-724	12/10/08	4.05	10.6	4.89	1.83 P	276
AKG-724	3/18/09	4.93	7.5	4.91	1.29	328
AKG-725	8/27/04	10.58				
AKG-725	9/20/04	10.53	12.1	5.34	7.60	438
AKG-725	10/19/04	9.99	12.1	--	5.60	444
AKG-725	11/23/04	6.69	11.8	5.72	8.09	486
AKG-725	12/28/04	3.99	9.4	5.72	7.50 P	473
AKG-725	2/1/05	4.54	8.0	5.68	9.60	435
AKG-725	3/2/05	7.41	9.1	4.48	6.85	454
AKG-725	3/31/05	5.75	9.1	5.67	6.75	445
AKG-725	4/26/05	6.77	10.1	5.70	6.80	390
AKG-725	5/26/05	8.70	10.6	5.79	6.73	475

Laboratory Analyses ¹											
Ammonia-N (mg/L)		Nitrite+ Nitrate-N (mg/L)		Total Persulfate N (mg/L)	Ortho Phosphorus (mg/L)		Total Phosphorus (mg/L)	Chloride (mg/L)	Total Dissolved Solids (mg/L)	Organic Carbon (mg/L)	
0.010	U	2.91	P	2.62	--	--	--	8.27	181	2	5
0.010	U	2.42		2.58	--	--	--	7.47	175	2	0
0.010	U	4.97		5.21	--	--	--	9.03	176	1	9
0.010	U	6.94		6.16	--	--	--	9.79	180	2	2
0.010	U	6.68		6.69	--	--	--	7.87 P	153	1	9
0.010	U	6.74		7.25	--	--	--	8.53	161	2	1
0.010	U	8.00		8.19	--	--	--	8.61	175	2	6
0.010	U	5.94	P	6.26	--	--	--	8.38	160	2	2
0.010	U	9.98		10.0	--	--	--	8.76	186	2	3
0.010	U	5.30		5.82	--	--	--	6.11	185	2	2
0.022		7.53		7.01	--	--	--	6.70	197	2	1
0.010	U	5.36		5.41	--	--	--	6.80 J	163	2	1
0.010	U	3.91		4.33	--	--	--	6.49	177	2	2
0.010	U	6.49		7.09	--	--	--	7.61	180	2	1
0.010	U	11.0		11.0	--	--	--	9.31	190	2	2
0.010	U	15.3		14.3	--	--	--	14.3	245	1	9
0.010	U	25.4		23.7	0.0074	0.0048	P	19.2	323	J	1
0.017		26.8		33.2	0.0072	0.0028	P	19.9	315		1
0.010	U	30.8		32.4	0.0054	0.0037		22.6	323		1
0.010	U	34.7		32.2	0.0110	0.0090		19.6	320	J	1
0.010	U	34.0		29.9	0.0090	0.0090		16.4	315		1
0.010	U	30.3		28.6	0.0094	0.0077		17.1	325		1
0.010	U	24.1		26.2	0.0097	0.0091	P	21.5	322		1
0.011		23.6		24.7	--	0.010	P	13.1	288		1
0.010	U	29.3		34.7	--	0.0473		24.6	362		1

Field Measurements						
Well Tag Number	Sample Date	Depth to Groundwater (ft below top of casing)	Temperature (C0)	pH (Standard Units)	Dissolved Oxygen (mg/L)	Conductivity (umhos/cm)
AKG-725	7/7/05	9.61	11.3	5.58	6.24	525
AKG-725	8/17/05	10.17	11.9	5.64	6.90	538
AKG-725	9/22/05	10.46	12.4	5.57	6.54	491
AKG-725	10/20/05	10.36	12.2	5.71	5.93	455
AKG-725	11/17/05	8.41	12.2	5.71	6.50	431
AKG-725	12/15/05	8.58	10.8	5.73	6.33	401
AKG-725	1/11/06	1.77	8.4	5.97	9.71	313
AKG-725	2/8/06	3.71	8.1	5.80	7.43	261
AKG-725	3/8/06	8.04	8.4	5.70	6.47	286
AKG-725	4/5/06	8.72	9.7	5.84	5.48	341
AKG-725	5/17/06	9.38	10.1	5.72	8.14	366
AKG-725	6/27/06	10.04	11.1	5.81	7.32	324
AKG-725	8/2/06	10.51	11.4	5.75	6.18 P	323
AKG-725	9/13/06	10.95	11.6	5.68	7.26 P	284
AKG-725	10/18/06	11.21	11.7	5.81	6.07	292
AKG-725	11/15/06	9.54	11.2	5.76	3.38	323
AKG-725	12/13/06	3.89	9.6	5.82	10.10 P	339
AKG-725	1/18/07	6.24	7.4	5.93	10.24 P	290
AKG-725	2/13/07	7.36	7.5	5.90	8.59 P	296
AKG-725	3/29/07	3.24	7.7	5.89	9.30 P	259
AKG-725	5/14/07	8.54	10.0	5.89	9.61	264
AKG-725	6/14/07	9.40	10.7	5.84	8.55	278
AKG-725	7/30/07	10.21	11.3	5.97	7.82 P	281
AKG-725	9/2/07	10.69	11.6	5.80	8.67	276
AKG-725	10/2/07	10.84	11.4	5.82	6.86	288
AKG-725	10/30/07	9.62	11.4	5.81	4.64	298
AKG-725	11/28/07	8.96	9.8	5.97	7.99	285

Laboratory Analyses ¹														
Ammonia-N (mg/L)		Nitrite+ Nitrate-N (mg/L)		Total Persulfate N (mg/L)		Ortho Phosphorus (mg/L)		Total Phosphorus (mg/L)		Chloride (mg/L)	Total Dissolved Solids (mg/L)		Organic Carbon (mg/L)	
0.010	U	35.1		42.7		--		0.0085		28.2	381		2 2	
0.010	U	35.5		37.4		--		0.0085		30.3	418		1.6	
0.010	U	29.0		30.7		--		0.0098		25.0	357		2.0	
0.010	U	24.5		22.8		--		0.010		20.4	307		1 9	
0.010	U	24.8		28.1		--		0.0094		18.7	287		1.8	
0.010	U	22.4		22.5		--		0.010		17.1	292		2 1	
0.010	U	13.8		11.8		--		0.0098		9.4	206		2 2	
0.010	U	10.4		10.8		--		0.011		8.12	177	P	2 2	
0.010	U	13.2		13.2		--		0.012		9.28	204		1.6	
0.010	U	16.1		16.8		--		0.0080		11.6	233		2 1	
0.010	U	19.0		19.0		--		0.0082		16.6	251		1.6	
0.010	U	13.8		10.2		--		0.0129		11.9	223		2.0	
0.010	U	10.6		25.0		--		0.0106		12.7	232		2 1	
0.010	U	10.5		9.84		--		0.0114		10.8	211		2 3	
0.010	U	10.0		8.20		--		0.0106		9.20	204		3 9	
0.010	U	9.83	P	9.92	P	--		0.0117	P	9.27	213		3 5	P
0.010	U	16.2		15.3		--		0.0116	P	16.6	P	232	1 5	P
0.010	U	16.1		16.5		--		--		11.4	211		2 5	
0.010	U	16.3		16.8		--		--		10.9	P	209	P	1.6
0.010	U	11.7		12.7		--		--		9.95	175		1.6	
0.010	U	10.1		11.4	P	--		--		7.84	175		1 5	
0.010	U	10.9		9.61		--		--		8.13	188		1.6	
0.010	U	10.7		11.4		--		--		9.88	201		2.0	
0.010	U	12.5	P	10.5		--		--		9.96	200		1.8	
0.010	U	12.8		11.1		--		--		9.69	211		1.6	
0.010	U	9.54		9.76		--		--		9.08	206		1.7	
0.010	U	10.4		10.0		--		--		7.93	191		1.7	

Field Measurements						
Well Tag Number	Sample Date	Depth to Groundwater (ft below top of casing)	Temperature (C0)	pH (Standard Units)	Dissolved Oxygen (mg/L)	Conductivity (umhos/cm)
AKG-725	1/4/08	5.17	8.0	5.84	8.80	252
AKG-725	1/31/08	7.04	7.0	5.87	9.07	257
AKG-725	2/28/08	7.55	7.6	5.86	9.36	249
AKG-725	4/1/08	7.64	8.4	5.84	7.28	235
AKG-725	5/7/08	8.96	9.3	5.89	9.49	229
AKG-725	6/18/08	9.27	9.9	5.88	8.06	234
AKG-725	7/23/08	9.77	10.9	5.78	7.25	238
AKG-725	9/9/08	9.88	11.5	5.84	5.40	243
AKG-725	10/8/08	10.33	11.5	5.77	7.68 P	234
AKG-725	11/13/08	5.81	11.7	5.83	8.61 P	290
AKG-725	12/10/08	6.47	10.1	5.78	8.36 P	365
AKG-725	3/19/09	7.74	7.6	5.73	9.04	319
AKG-726	8/27/04	10.61				
AKG-726	9/21/04	10.57	--	--	--	--
AKG-726	10/19/04	10.05	10.2	--	0.00	428
AKG-726	11/23/04	6.97	10.2	6.62	0.00	418
AKG-726	12/28/04	4.05	10.3	6.54	0.18 P	415
AKG-726	2/1/05	4.57	10.4	6.53	0.90	428
AKG-726	3/2/05	7.46	10.5	6.17	0.13	432
AKG-726	3/31/05	5.74	10.5	5.80	0.07	426
AKG-726	4/26/05	6.78	10.7	6.61	0.21	435
AKG-726	5/26/05	8.73	10.8	6.62	0.06	440
AKG-726	7/7/05	9.65	10.8	6.47	--	424
AKG-726	8/17/05	10.24	10.2	6.48	0.33	444
AKG-726	9/22/05	10.51	10.1	5.77	0.00	436
AKG-726	10/20/05	10.40	10.2	6.78	0.67	417

Laboratory Analyses ¹														
Ammonia-N (mg/L)		Nitrite+ Nitrate-N (mg/L)		Total Persulfate N (mg/L)		Ortho Phosphorus (mg/L)		Total Phosphorus (mg/L)		Chloride (mg/L)	Total Dissolved Solids (mg/L)		Organic Carbon (mg/L)	
0.010	U	11.9		12.0		--		--		7.49 P	164		1.6	
0.010	U	12.0		13.1		--		--		6.72	173		1.6	
0.010	U	12.1		12.5		--		--		6.04	179		1.7	
0.010	U	12.0	P	12.2		--		--		6.00	169		1.3	
0.010	U	7.53		6.92		--		--		4.85	178		1.6	
0.010	U	6.42		6.59		--		--		3.91	176		1.7	
0.010	U	6.58		6.15		--		--		3.89	173		2.0	
0.010	U	7.63		7.82		--		--		4.18	155		1.7	
0.010	U	8.09		8.53		--		--		4.23	187		1.7	
0.010	U	12.90		13.50		--		--		8.85	193		1.5	
0.010	U	20.4		20.4		--		--		14.1	240		1.8	
0.010	U	20.1		17.5		--		--		10.5	184		2.1	
--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
0.229		0.010	U	0.272		0.0407		0.136	P	18.7	261		1.5	
0.228		0.021		0.300		0.0067		0.146		17.3	261		1.7 (TOC)	
0.216		0.010		0.18		0.0100		0.146		14.7	256	J	1.4 (TOC)	
0.220		0.020		0.24		0.0075		0.244		13.8	276		1.7 (TOC)	J
0.211		0.012		0.21		0.0070		0.134		13.8	275		1.3 (TOC)	
0.248		0.012		0.24		0.0070		0.155	P	14.0	284		1.6 (TOC)	
0.170		0.030		0.18		--		0.129	P	14.0	308		1.3 (TOC)	
0.216		0.011		0.24		--		0.155		13.6	284		2.7	J
0.212		0.011		0.24		--		0.133		12.2	292		1.4 (TOC)	
0.222		0.022		0.17		--		0.120		13.0	295		1.4 (TOC)	
0.222		0.022		0.344		--		0.153		12.8	286		1.6 (TOC)	
0.221		0.037		0.319		--		0.1340		12.7	264		1.8 (TOC)	

Field Measurements						
Well Tag Number	Sample Date	Depth to Groundwater (ft below top of casing)	Temperature (C0)	pH (Standard Units)	Dissolved Oxygen (mg/L)	Conductivity (umhos/cm)
AKG-726	11/17/05	8.47	--	--	--	--
AKG-726	12/15/05	8.60	10.2	6.48	0.27	420
AKG-726	1/11/06	1.86	10.1	6.71	0.85	420
AKG-726	2/8/06	3.82	10.3	6.69	0.29	401
AKG-726	3/8/06	8.10	10.2	6.35	0.02	378
AKG-726	4/5/06	8.73	10.5	6.60	0.22	373
AKG-726	5/18/06	9.45	10.8	6.45	0.88	359
AKG-726	6/27/06	10.11	11.7	6.63	0.91	372
AKG-726	8/3/06	10.59	10.6	6.49 P	0.22	382
AKG-726	9/14/06	11.01	10.4	6.48 P	0.26	364
AKG-726	10/19/06	11.25	10.6	6.67	0.30	382
AKG-726	11/15/06	9.57	--	--	--	--
AKG-726	12/13/06	4.02	10.2	6.54	0.14 P	381
AKG-726	1/18/07	6.33	10.1	6.59	0.00 P	362
AKG-726	2/13/07	7.45	10.3	6.63	0.06 P	371
AKG-726	3/29/07	3.39	10.2	6.59	0.05 P	352
AKG-726	5/15/07		10.3	6.69	0.05	366
AKG-726	6/14/07	9.47	10.6	6.62	0.00	365
AKG-726	7/30/07	10.29	11.1	6.74	0.63 P	353
AKG-726	9/2/07	10.76	10.1	6.60	0.14	354
AKG-726	10/2/07	10.91	10.0	6.62	0.01	378
AKG-726	10/31/07	9.67	10.0	6.57	0.07	378
AKG-726	11/28/07	9.03	9.9	6.66	0.09	369
AKG-726	1/4/08	5.24	--	--	--	--
AKG-726	1/31/08	7.14	10.1	6.61	0.09	347
AKG-726	2/28/08	7.65	--	--	--	--
AKG-726	4/1/08	7.70	--	--	--	--

Laboratory Analyses ¹									
Ammonia-N (mg/L)	Nitrite+Nitrate-N (mg/L)	Total Persulfate N (mg/L)	Ortho Phosphorus (mg/L)	Total Phosphorus (mg/L)	Chloride (mg/L)	Total Dissolved Solids (mg/L)	Organic Carbon (mg/L)		
--	--	--	--	--	--	--	--	--	--
0.227	0.043	0.24	--	0.264	12.1	260	1.8 (TOC)		
0.224	0.049	0.31	--	0.124	12.1	285	1.8 (TOC)		
0.205	0.051	0.324	--	0.113	12.1	277	P	1.7 (TOC)	
0.195	0.036	0.303	--	0.131	12.1	268	1.6 (TOC)		
0.206	0.333	0.386	--	0.148	12.3	261	1.9 (TOC)		
0.209	0.049	0.315	--	0.135	10.2	246	1.4 (TOC)		
0.195	0.075	0.356	--	0.132	11.4	243	1.6 (TOC)		
0.219	0.080	0.352	--	0.150	12.8	257	1.8 (TOC)		
0.211	0.103	0.311	--	0.135	12.0	246	1.7(TOC)		
0.207	0.026	0.357	--	0.193	13.2	262	2.6(TOC)		
--	--	--	--	--	--	--	--	--	--
0.197	0.010	U 0.290	P	0.1280	13.9 P	242	3 2	P	
0.203	0.010	0.266	--	--	11.7	257	1.7		
0.210	0.038	0.274	--	--	11.6 P	247	P	1.8	
0.198	0.010	U 0.285	--	--	9.48	236	2 9		
0.204	0.010	U 0.210	P	--	8.49	215	1 5		
0.226	0.010	U 0.296	--	--	9.57	230	1.6		
0.199	0.010	U 0.257	--	--	10.6	242	1.6		
0.231	0.010	UP 0.285	--	--	11.0	242	2 3		
0.205	0.010	U 0.288	--	--	11.1	244	1.6		
0.197	0.010	UJ 0.373	--	--	11.7	240	1.0	U	
0.200	0.020	0.378	--	--	11.3	228	1.8	TOC	
--	--	--	--	--	--	--	--	--	--
0.193	0.025	0.34	--	--	11.1	235	1.7	TOC	
--	--	--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--	--	--

Field Measurements						
Well Tag Number	Sample Date	Depth to Groundwater (ft below top of casing)	Temperature (C0)	pH (Standard Units)	Dissolved Oxygen (mg/L)	Conductivity (umhos/cm)
AKG-726	5/7/08	9.07	10.2	6.57	0.10	340
AKG-726	6/18/08	9.35	10.7	6.65	0.18	360
AKG-726	7/23/08	9.83	10.7	6.45	0.00	365
AKG-726	9/9/08		--	--	--	--
AKG-726	10/8/08	10.43	10.4	6.65		366
AKG-726	11/13/08		--	--	--	--
AKG-726	12/10/08	6.55	--	--	--	--
AKG-726	3/19/09	7.81	10.1	6.45	0.17	356
AKG-727	8/27/04	9.18				
AKG-727	9/20/04	8.13	13.2	5.21	0.00	418
AKG-727	10/18/04	7.68	12.8	NA	2.20	393
AKG-727	11/22/04	4.36	11.8	5.38	1.00	379
AKG-727	12/28/04	1.31	10.4	5.37	4.50 P	407
AKG-727	2/1/05	1.64	9.5	5.32	4.58	360
AKG-727	3/3/05	4.98	9.4	5.41	3.02	354
AKG-727	3/30/05	3.54	9.1	5.16	3.64	364
AKG-727	4/25/05	4.14	10.4	5.36	3.55	379
AKG-727	5/25/05	6.09	11.1	5.35	3.38	382
AKG-727	7/6/05	7.02	11.5	5.21	2.32	379
AKG-727	8/16/05	7.68	13.5	5.28	3.22	366
AKG-727	9/21/05	8.04	13.7	5.19	2.53	383
AKG-727	10/19/05	7.95	12.5	5.53	1.13	401
AKG-727	11/17/05	6.12	12.1	5.36	1.70	396
AKG-727	12/14/05	6.07	10.5	5.26	3.04	360
AKG-727	1/10/06		--2	--2	--2	--2
AKG-727	2/7/06	1.08	9.1	5.39	3.82	264

Laboratory Analyses ¹															
Ammonia-N (mg/L)		Nitrite+ Nitrate-N (mg/L)		Total Persulfate N (mg/L)		Ortho Phosphorus (mg/L)		Total Phosphorus (mg/L)		Chloride (mg/L)		Total Dissolved Solids (mg/L)		Organic Carbon (mg/L)	
0.218		0.020		0.341		--		--		12.2		238		1.8	TOC
0.225		0.023				--		--		11.0		236		--	
0.223		0.028		0.300		--		--		10.6		223		1.7	
--		--		--		--		--		--		--		--	
1.01	J	0.017	J	0.804	J	--		--						4.5	J
--	--	--	--	--	--	--		--		--		--	--	--	
--	--	--	--	--	--	--		--		--		--	--	--	
0.209		0.012		0.279		--		--		9.66		221		1.8	
0.010	U	12.7		12.5		0.0079		0.0027	P	21.0		266	J		
0.018		12.3		12.0		0.0062		0.0026	P	18.3		255		1.8	
0.010	U	13.3		14.0		0.0047		0.0029		18.0		240		2.3	
0.010	U	22.8		23.6		0.0066		0.0034		18.2		268	J	2.4	
0.010	U	19.1		21.8		0.0044		0.0024		14.7		249		2.3	
0.010		15.4		16.1		0.0052		0.0037		13.8		231		2.0	
0.010	U	19.2		22.7		0.0049		0.0043	P	14.9		254		2.2	
0.012		18.9		19.3		--		0.0034	P	15.5		264		1.8	
0.010	U	18.9		21.1		--		0.0010	U	15.9		266		2.3	J
0.010	U	17.7		16.9		--		0.0039		16.4		261		2.1	
0.010	U	15.7		15.8		--		0.0035		15.5		255		2.3	
0.010	U	13.2		14.5		--		0.0037		17.6		254		2.2	
0.010	U	12.3		11.9		--		0.0032		19.5		262		2.5	
0.010	U	14.0		14.4		--		0.0034		19.5		254		2.1	
0.010	U	11.8		10.7		--		0.0039		14.9		240		2.3	
--2		--2		--2		--2		--2		--2		--2		--2	
0.010	U	6.70		6.16		--		0.0052		8.46		193	P	3.2	

Field Measurements						
Well Tag Number	Sample Date	Depth to Groundwater (ft below top of casing)	Temperature (C0)	pH (Standard Units)	Dissolved Oxygen (mg/L)	Conductivity (umhos/cm)
AKG-727	3/7/06	7.63	8.9	5.33	4.68	270
AKG-727	4/4/06	6.27	10.1	5.31	4.48	291
AKG-727	5/17/06	6.93	11.2	5.22	4.34	268
AKG-727	6/26/06	7.57	12.7	5.42	3.64	254
AKG-727	8/2/06	8.11	12.6	5.36	4.27 P	264
AKG-727	9/13/06	8.65	12.0	5.38	1.93 P	268
AKG-727	10/18/06	8.95	12.3	5.54	0.59	309
AKG-727	11/14/06	7.29	11.2	5.50	1.30	303
AKG-727	12/12/06	1.94	10.7	5.57	6.17 P	249
AKG-727	1/17/07	3.50	8.3	5.44	6.17 P	234
AKG-727	2/12/07	4.95	8.4	5.51	5.91 P	251
AKG-727	3/28/07	1.31	8.9	5.58	2.58 P	241
AKG-727	5/14/07	6.13	11.1	5.44	3.96	254
AKG-727	6/13/07	6.97	10.4	5.46	3.25	278
AKG-727	7/30/07	7.91	12.4	5.51	2.32 P	269
AKG-727	9/2/07	8.39	12.7	5.31	1.35	268
AKG-727	10/1/07	8.68	12.4	5.35	0.68	276
AKG-727	10/30/07	7.41	12.1	5.41	2.18	268
AKG-727	11/27/07	6.75	11.0	5.46	2.35	251
AKG-727	1/3/08	2.46	8.8	5.49	4.08	225
AKG-727	1/30/08	4.90	7.5	5.55	6.49	223
AKG-727	2/27/08	5.27	7.7	5.62	5.08	220
AKG-727	4/1/08	5.15	8.8	5.45	3.45	219
AKG-727	5/6/08	6.55	8.9	5.50	3.98	213
AKG-727	6/18/08	6.86	10.4	5.36	--	217
AKG-727	7/22/08	7.33	13.0	5.33	3.48	225
AKG-727	8/26/08	7.85	14.3	5.40	2.35	199

Laboratory Analyses ¹															
Ammonia-N (mg/L)		Nitrite+ Nitrate-N (mg/L)		Total Persulfate N (mg/L)		Ortho Phosphorus (mg/L)		Total Phosphorus (mg/L)		Chloride (mg/L)		Total Dissolved Solids (mg/L)		Organic Carbon (mg/L)	
0.010	U	11.6		8.58		--		0.0071		10.5		199		2.9	
0.010	U	11.0		10.4		--		0.0050	U	9.90		202		2.2	
0.010	U	5.67		6.53		--		0.0050	U	6.48		196		2.1	
0.010	U	2.81		3.16		--		0.0053		5.73		181		2.2	
0.010	U	2.06		2.15		--		0.0038		5.27		182		2.2	
0.010	U	0.535		0.745		--		0.0035		7.59		193		2.7	
0.010	U	0.896		1.08		--		0.0024		9.89		218		2.8	
0.010	U	1.86	P	2.25	P	--		0.0040	P	9.54		197		3.7	P
0.010	U	4.53		4.66		--		0.0043	P	13.8	P	170		4.9	P
0.010	U	6.61		6.72		--		--		8.47		163		3.3	
0.010	U	6.30		6.25		--		--		8.04	P	174	P	2.3	
0.010	U	6.12		6.69		--		--		6.80		166		2.4	
0.010	U	6.96		6.22	P	--		--		7.65		165		2.3	
0.010	U	7.63		7.89		--		--		7.91		193		2.3	
0.010	U	8.45		7.19		--		--		8.07		188		3.6	
0.010	U	6.30	JP	6.28		--		--		8.05		197		2.5	
0.010	U	5.43		4.87		--		--		7.18		211		2.2	
0.010	U	4.62		5.41		--		--		7.57		169		1.9	
0.010	U	2.84		2.88		--		--		6.41		176		2.2	
0.010	U	4.17		4.11		--		--		4.80		152		2.4	
0.010	U	5.10		5.68		--		--		4.22	P	158		2.4	
0.010	U	4.57		4.76		--		--		4.51		147		2.9	
0.010	U	4.19	P	4.51		--		--		4.15		148		2.2	
0.010	U	5.23		5.15		--		--		4.58		163		2.2	
0.010	U	4.08		4.37		--		--		4.17		161		2.3	
0.010	U	5.20		4.50		--		--		4.72		157		2.2	
0.010	U	2.85		3.05		--		--		4.35		154		2.20	

Field Measurements						
Well Tag Number	Sample Date	Depth to Groundwater (ft below top of casing)	Temperature (C°)	pH (Standard Units)	Dissolved Oxygen (mg/L)	Conductivity (umhos/cm)
AKG-727	9/8/08	7.55	13.6	5.42	1.98	209
AKG-727	10/7/08	8.02	13.0	5.30	2.04 P	216
AKG-727	11/12/08	3.22	11.5	5.64	2.78 P	226
AKG-727	12/9/08	3.94	9.9	--	3.71 P	219
AKG-727	3/18/09	5.14	7.8	5.41	3.01	240

Laboratory Analyses ¹												
Ammonia-N (mg/L)		Nitrite+ Nitrate-N (mg/L)		Total Persulfate N (mg/L)		Ortho Phosphorus (mg/L)		Total Phosphorus (mg/L)		Chloride (mg/L)	Total Dissolved Solids (mg/L)	Organic Carbon (mg/L)
0.010	U	2.88		3.06		--		--		4.25 J	129	2 2
0.010	U	2.82		3.43		--		--		5.03	166	2 1
0.010	U	4.37		4.30		--		--		5.09	161	2.4
0.010	U	3.95		3.77		--		--		4.61	156	2 3
0.010	U	4.65		4.99		--		--		4.86	158	2 1

¹ All samples were field-filtered (0.45 um) except AKG726. From the start of the study until July 7, 2005, AKG726 nitrogen and phosphorus samples were filtered at MEL. The August 17, 2005 AKG726 samples for total organic carbon and total phosphorus were filtered at MEL. After August 17, 2005, AKG726 samples were not filtered.

*Meter was too wet to function.

**Lab/Field split quality assurance outside acceptable limits. (Lab result: 246 umhos/cm).

² Monitoring well was flooded.

³ We could not locate the well in tall grass.

⁴ Relative standard deviation of duplicates was outside the 7% acceptance limit.

U: Analyte was not detected at or above the reported result.

P: Duplicate result for that date did not meet the precision objective for that analyte (7% RSD for all analytes except chloride and organic carbon which were 10%) .

(Nooksack 2\Report\Final Report 2010\Data appendix.xlsx)

Table S.2. Water quality results from upgradient private wells. See Appendix B for driller's logs.

Well Tag Number	Sample Date	Temperature (C°)	pH (Standard Units)	Conductivity (umhos/cm)	Dissolved Oxygen (mg/L)	Ammonia-N (mg/L)	Nitrate+ Nitrite-N (mg/L)	Total Nitrogen (mg/L)	Chloride (mg/L)	Total Dissolved Solids (mg/L)
ALQ013	3/11/2008	7.6	7.1	573	0.0	0.194	0.020	0.394	16.0	--
ALQ013	4/2/2008	7.8	6.7	524	0.0	0.218	0.014	0.491	17.8	364
APM737	3/11/2008	10.0	6.4	380	0.0	0.255	0.021	0.689	17.1	--

(Z:\Nooksack2—older files....Upgradient well\Results.xlsx-both wells tab)

Appendix T. Precipitation, Surplus Water, and Air Temperature Data.

Table T.1. Monthly precipitation at or near the study site in inches. Most data are from the Ecology on-site weather station. Data for intervals when the weather station was down are from the wunderground.com site “KWALYNDE1” 3 miles southeast of the study site (between N. Pine Ct. and 19th St. close to the intersection of Guide Meridian and Main St., Lynden) or the on-site WSU weather station. For daily precipitation totals see Y: Shared files\Barb\Nooksack 2—older files\Report\precipitation.xlsx.Precip appendix tab&(Nooksack 2\Report\Final Report 2010\Precipitation_May_11.xlsx—Precip appendix tab---Need to add daily data for Jan-March 2009. Raw data is on Nooksack 2—older\Weather data\Dec_08 to March 09.xlsx and Download 06_17_09.xlsx)

	2004	2005	2006	2007	2008	2009
January	5.02	4.29	12.45	6.63	4.64	8.95
February	2.28	2.07	2.50	4.26	2.58	1.78
March	4.09	5.89	1.61	6.12	3.87	4.01
April	0.74	3.90	2.55	2.70	1.77	
May	2.64	0.25	1.99	1.48	2.00	
June	1.18	1.58	0.56	1.44	2.22	
July	0.51	0.88	1.23	1.48	3.31	
August	2.61	1.24	3.63	2.54	5.02	
September	4.21	1.55	2.28	4.53	0.84	
October	3.29	7.13	1.95	4.52	2.82	
November	9.43	3.00	11.42	3.17	11.67	
December	7.72	4.58	5.89	7.52	3.68	
Totals	43.7	36.4	48.1	46.4	44.4	

(My Doc's\...Nooksack 2\Report\final report\evap_Abbotsford_June_11.xlsx—data 04-10 tab)

Table T.2. Monthly surplus water estimates (feet) representing the difference between precipitation at the study site and evapotranspiration at the Abbotsford, B.C. airport.

	2004	2005	2006	2007	2008	2009
Jan	0.37	0.31	0.99	0.49	0.34	0.69
Feb	0.10	0.06	0.13	0.28	0.13	0.07
March	0.17	0.33	-0.02	0.37	0.19	0.23
Total	0.64	0.70	1.10	1.15	0.66	0.99

(...evap_Abbotsford_Mar_01_13.xls—Spring surplus tab)

Table T.3. Air temperature data from the WSU on-site weather station. Joan has compiled but needs to be zipped. (Y:\Shared\BARB\Nooksack 2\Report\Temperature.xlsx—Data from Lynn compiled tab)

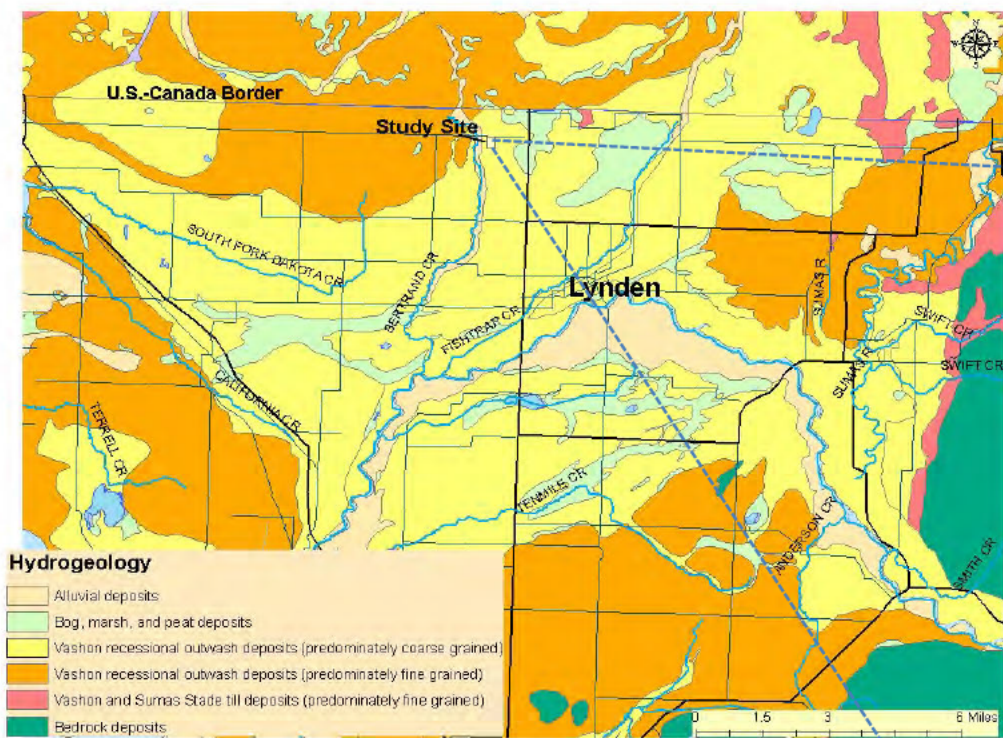


Figure 4. Local surficial geology of the study area from Jones (1999).

Figure 5. Location of wells used in Figure 6 cross-sections. The blue dots represent study monitoring wells; pink dots domestic wells. The red line is the study area boundary.

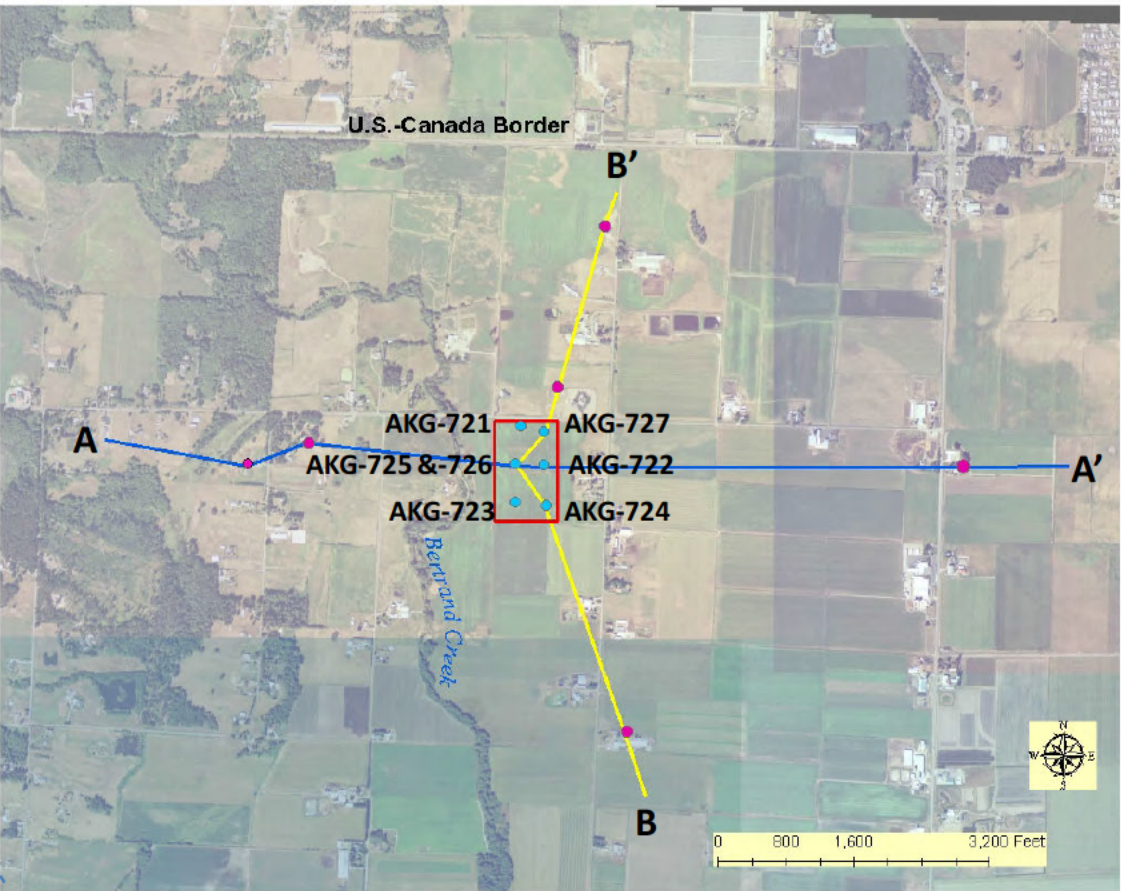


Plate 1. Hydrogeologic data.

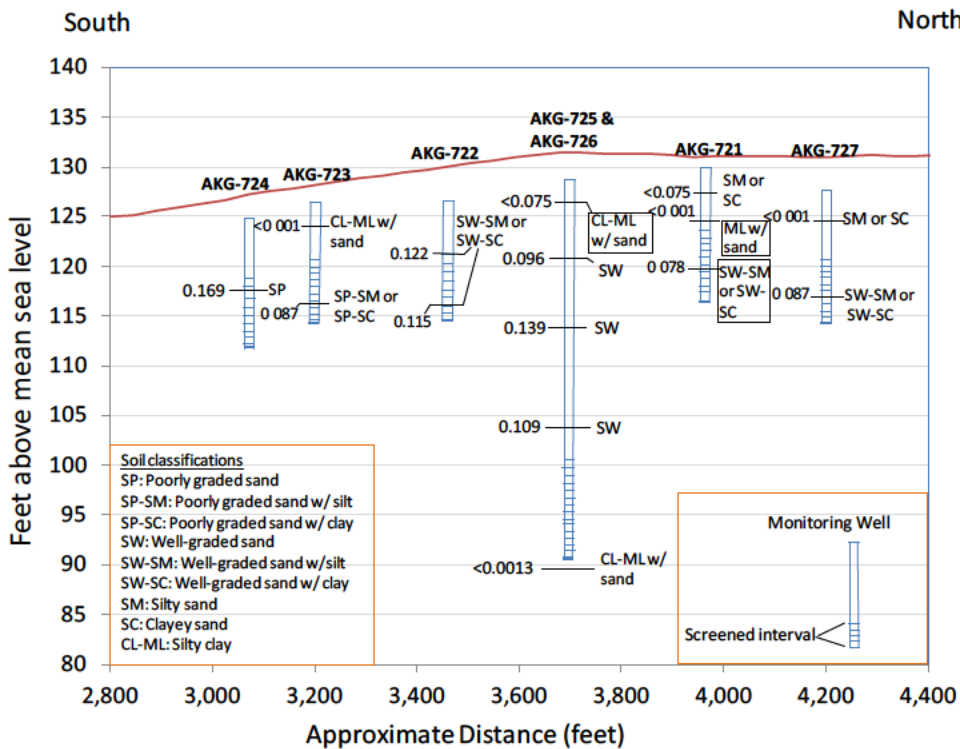


Figure 26. Soil classifications and d_{10} values for soil samples projected on land surface cross-section B-B'.

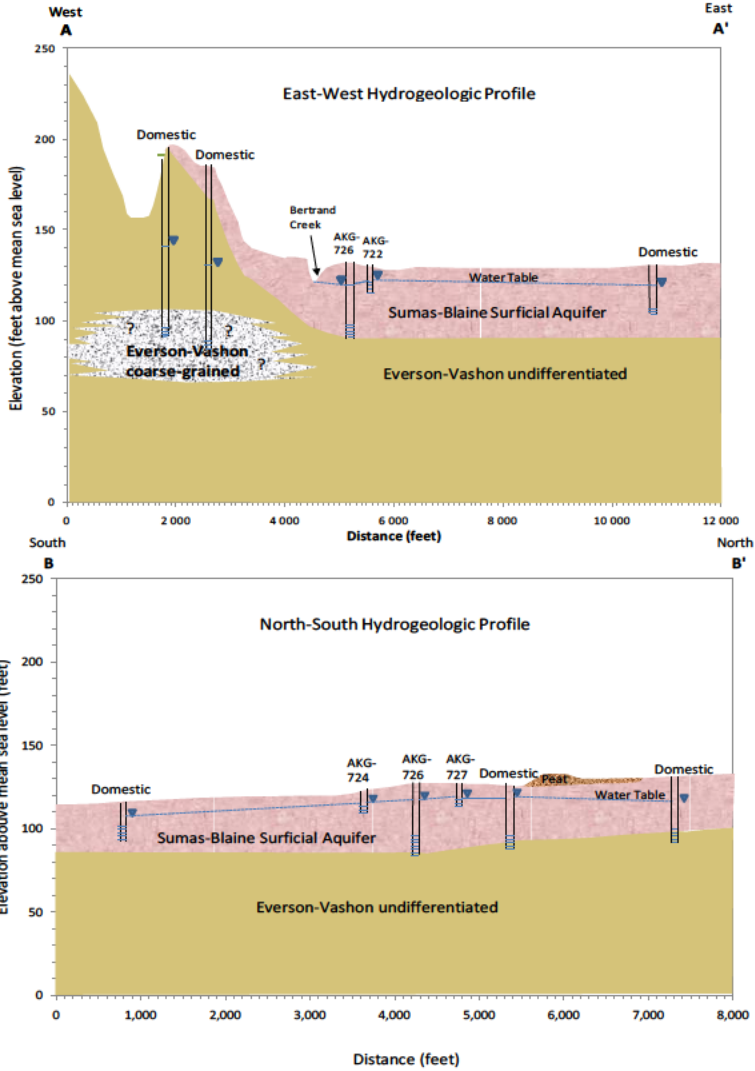


Figure 6. Generalized hydrogeologic cross-sections from Figure 5.

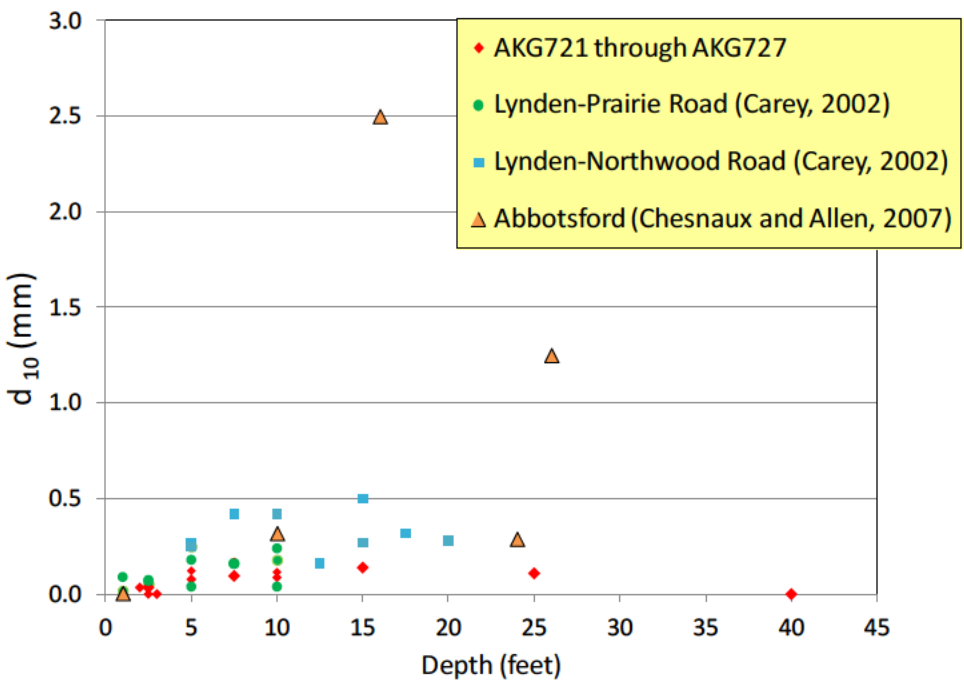


Figure 42. Effective grain size (d_{10}) values for drilling samples from monitoring wells in the U.S. and from one well near Abbotsford, B.C. See Figure 43 for locations.

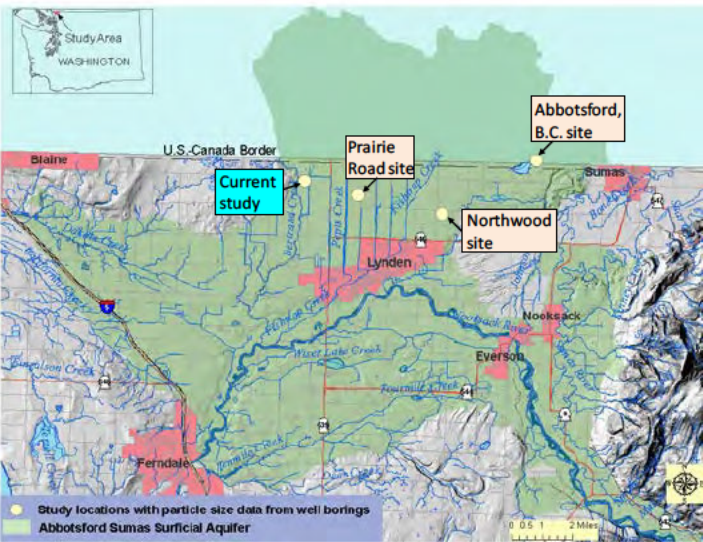


Figure 43. Locations of particle size analysis samples from well borings (Chesnaux and Allen, 2007 and Carey, 2002).

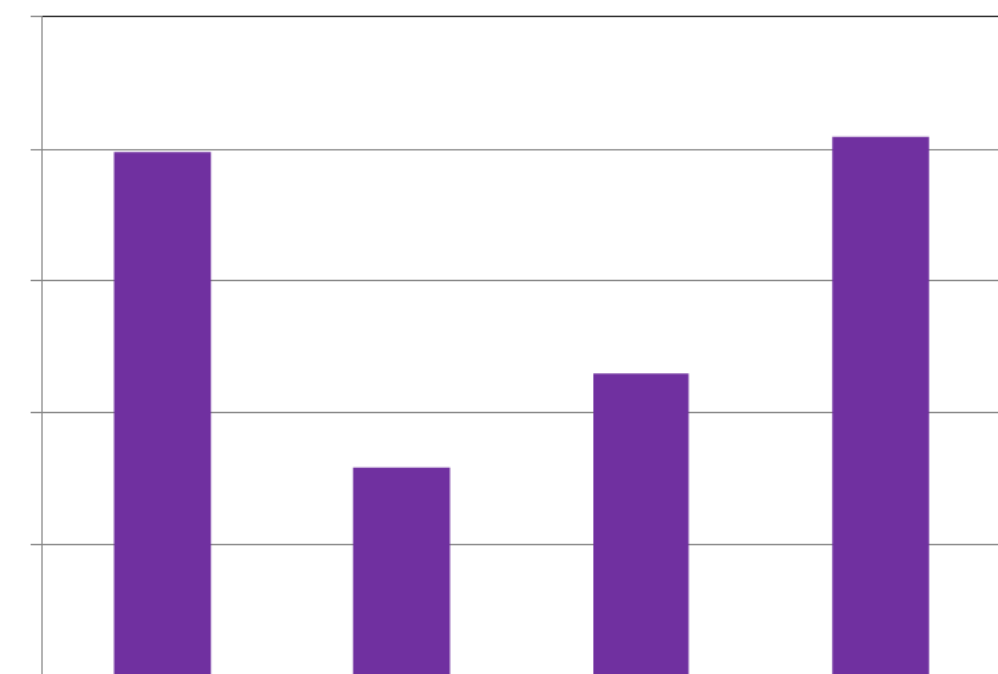
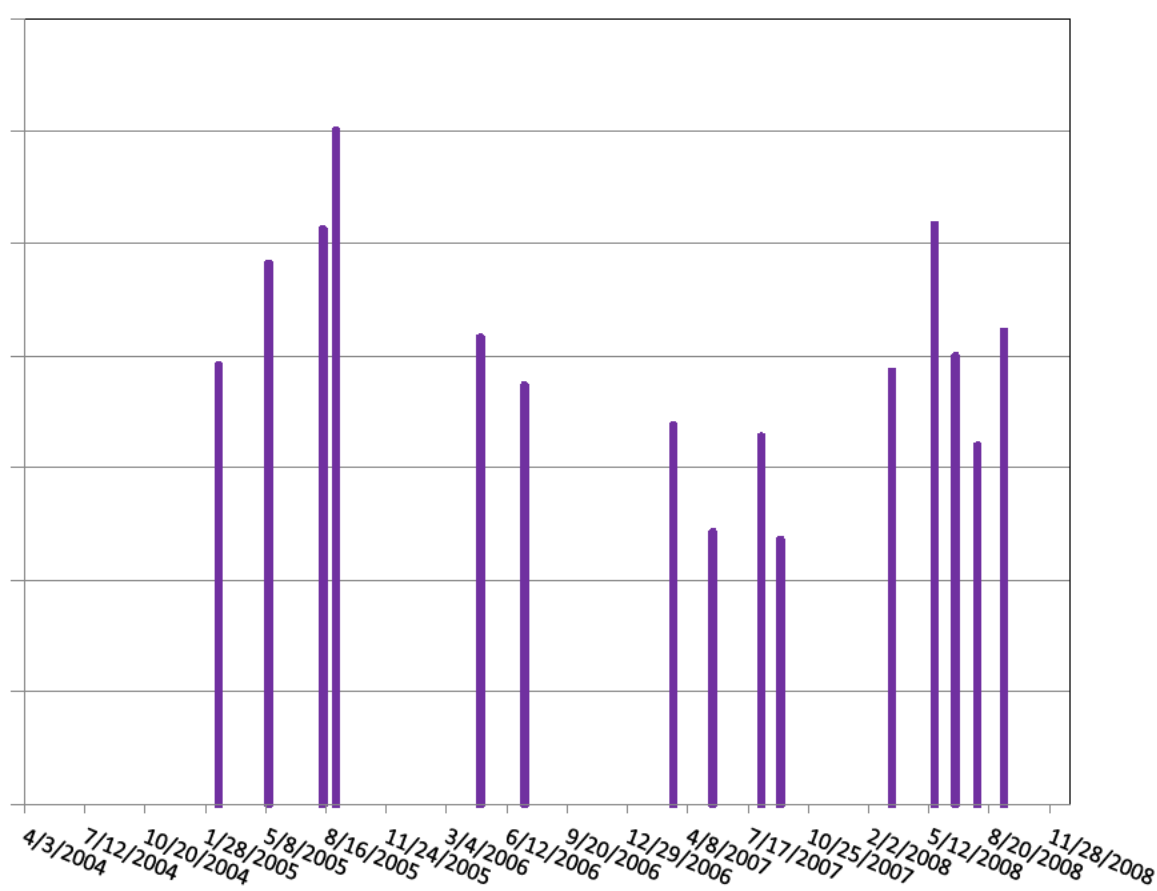
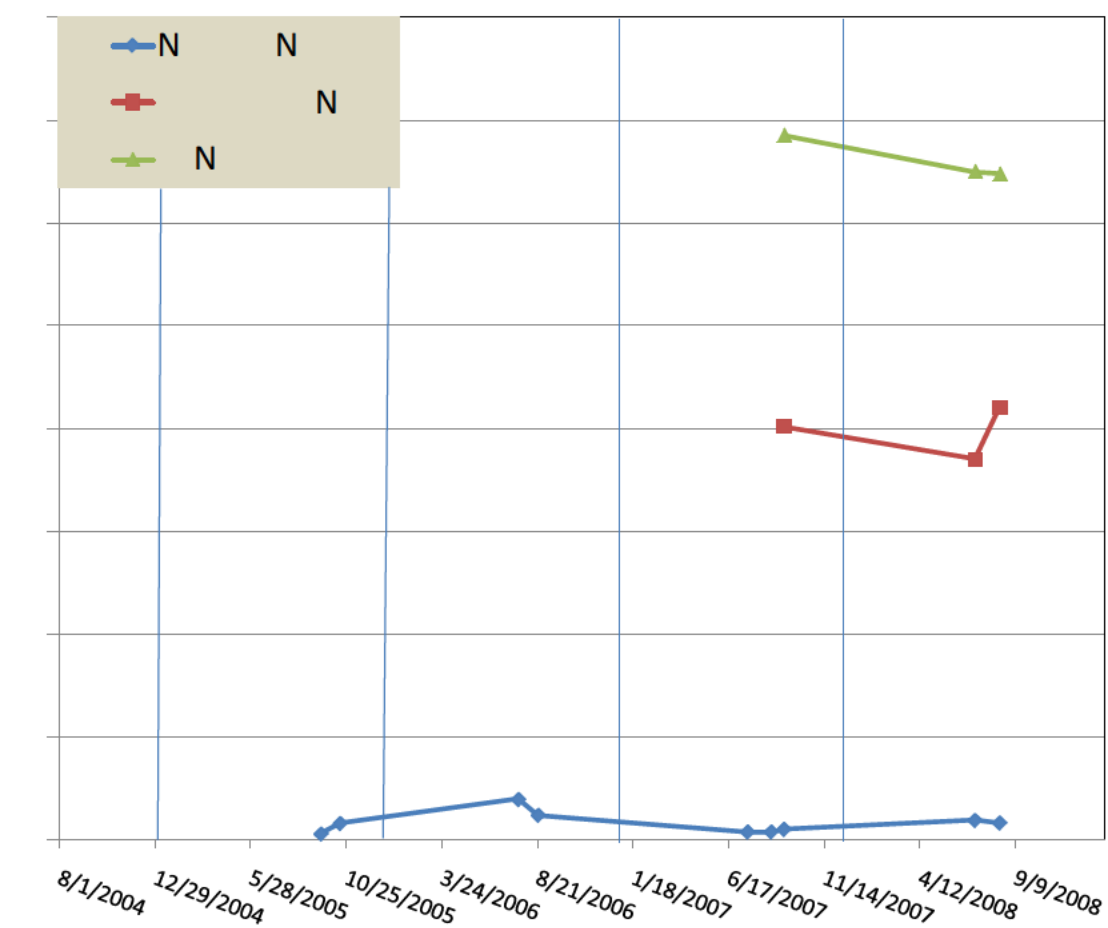
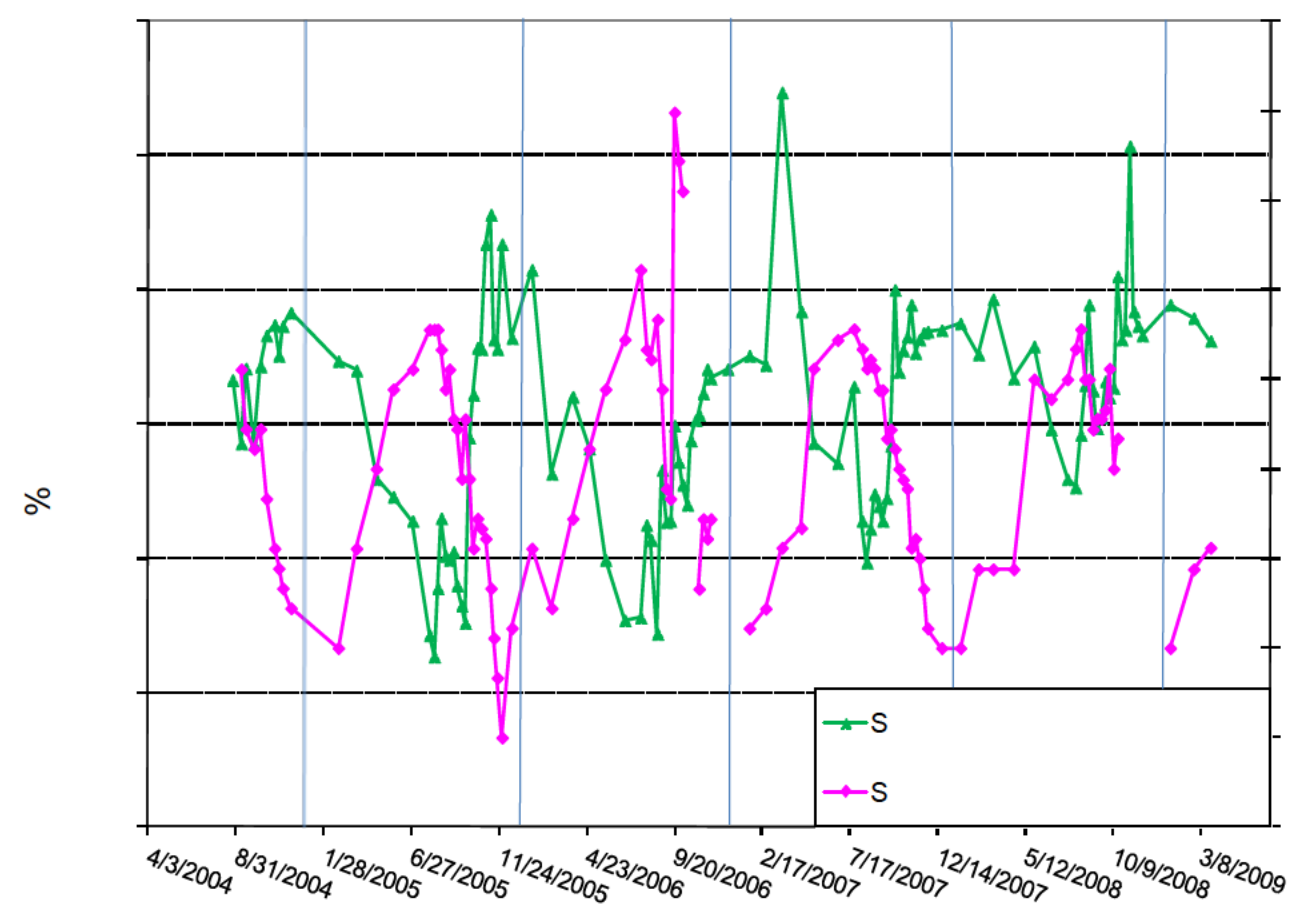
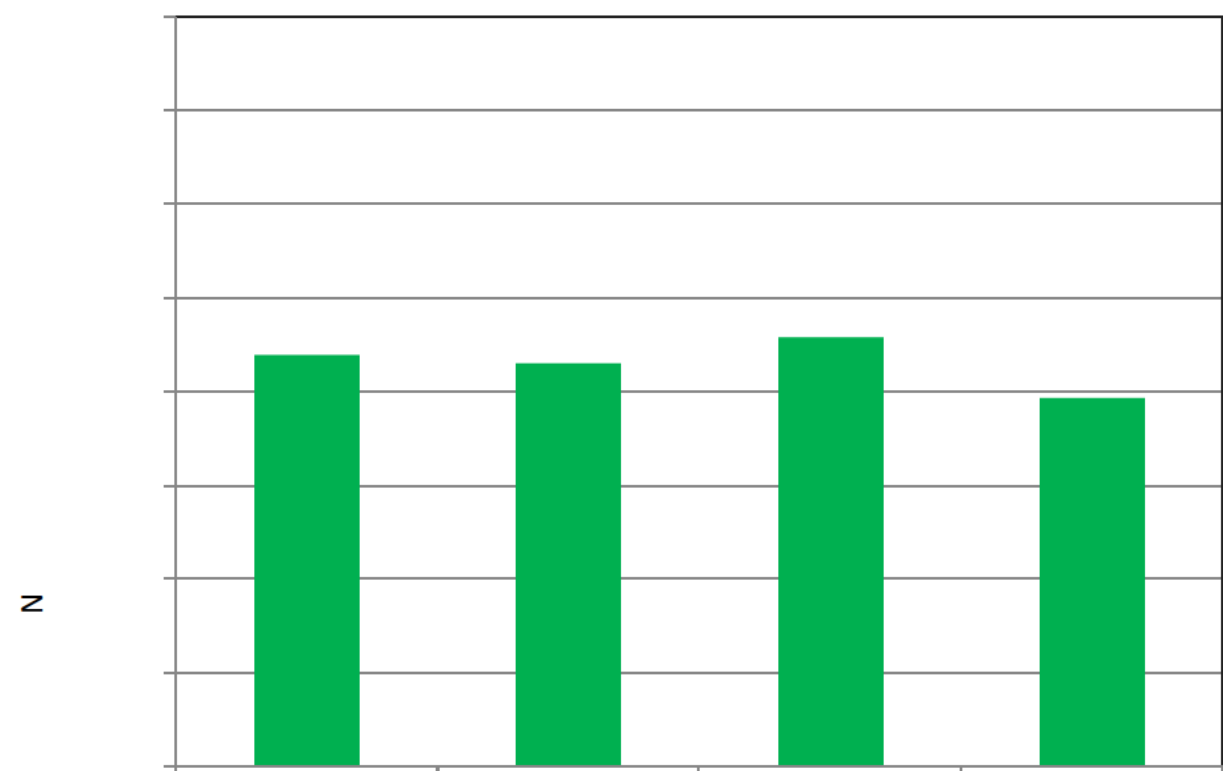
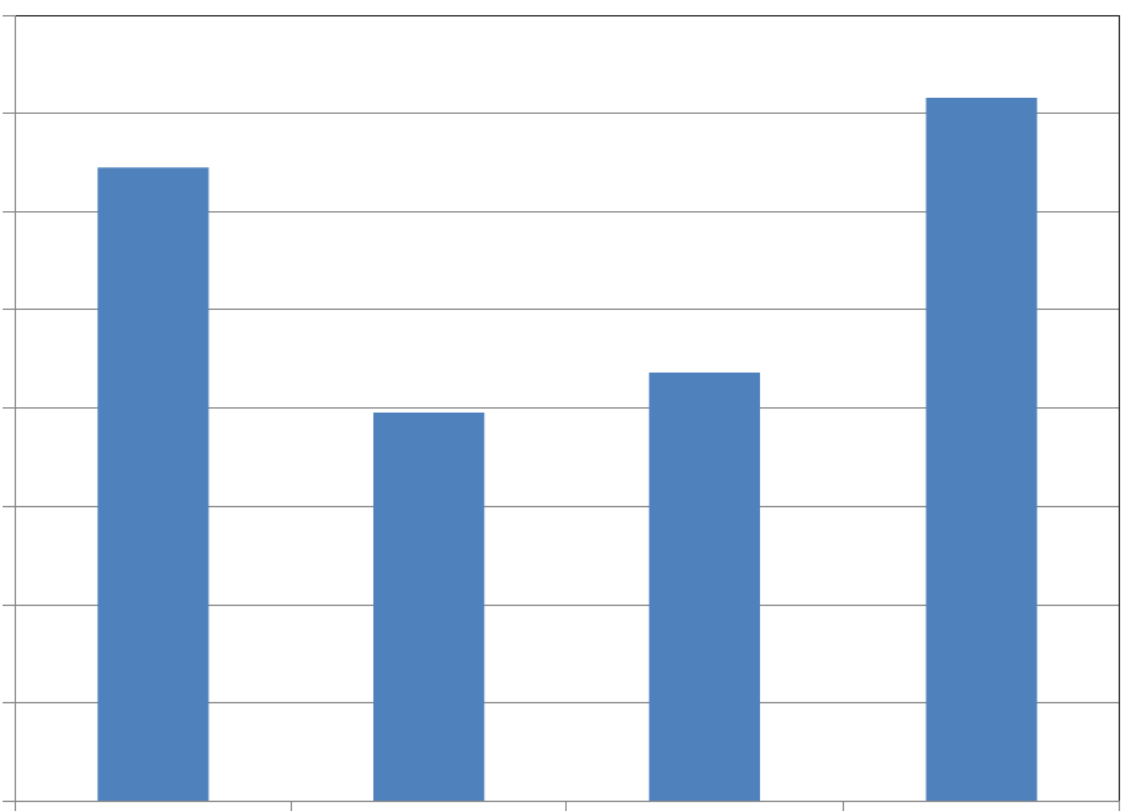
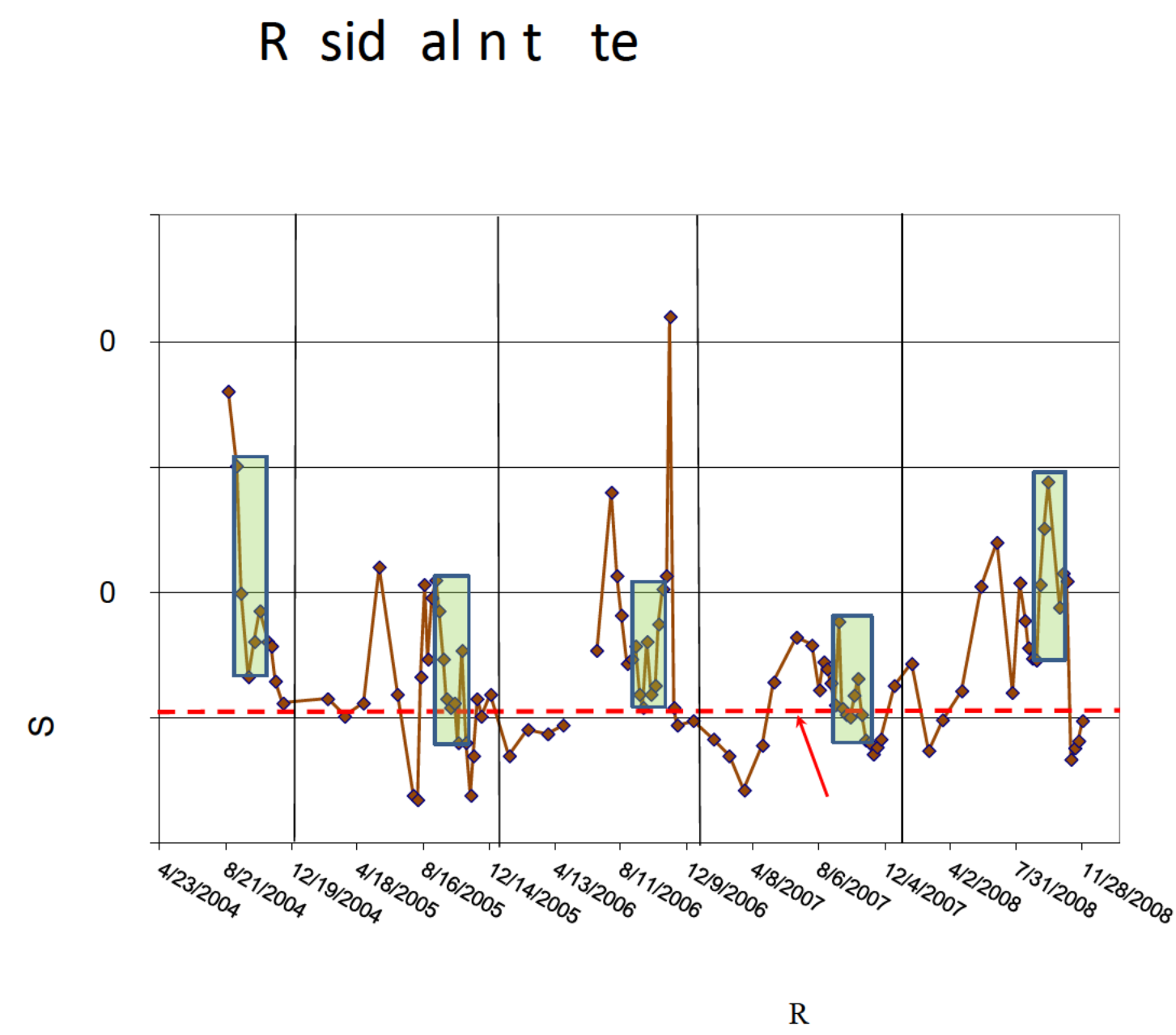
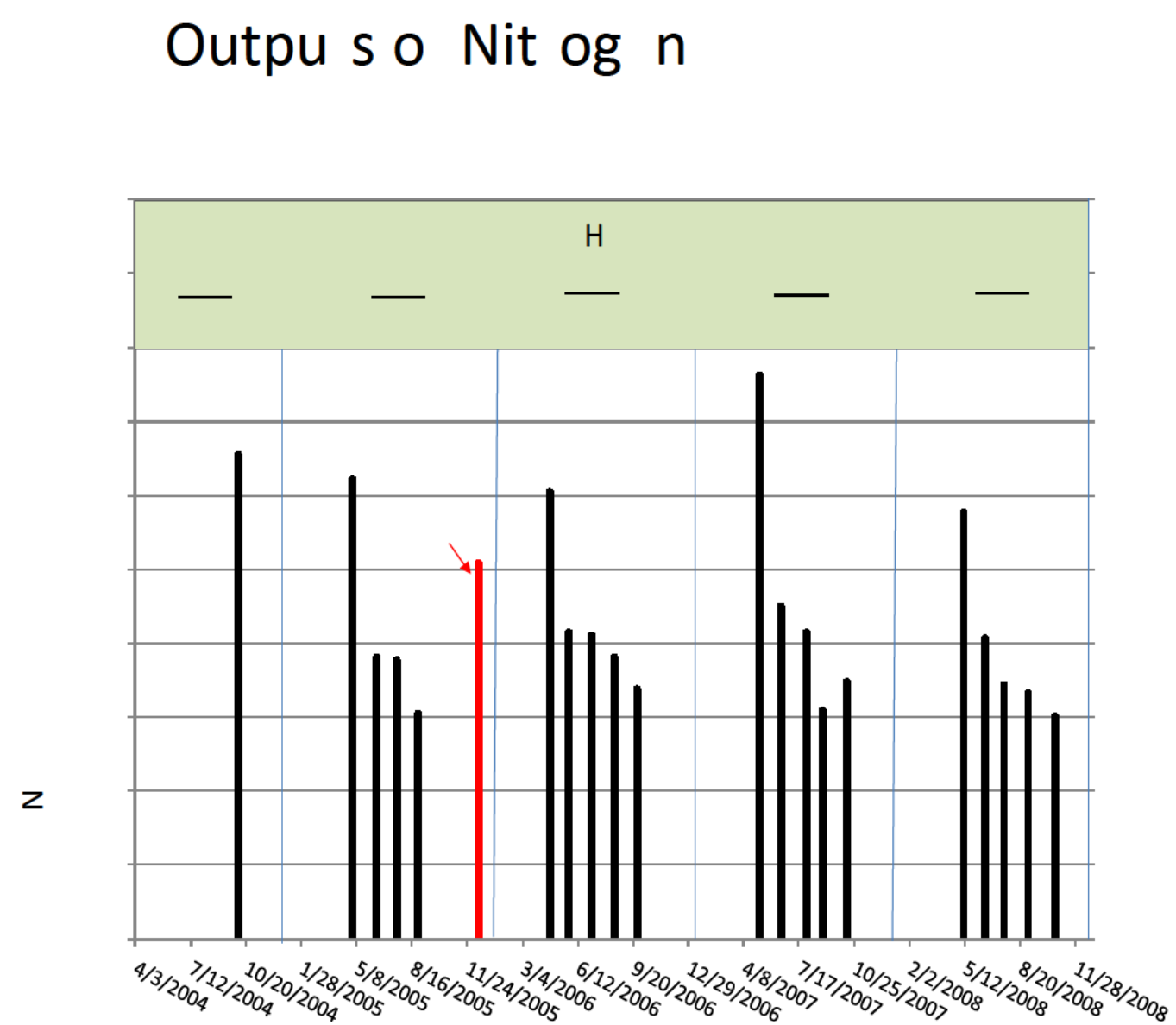
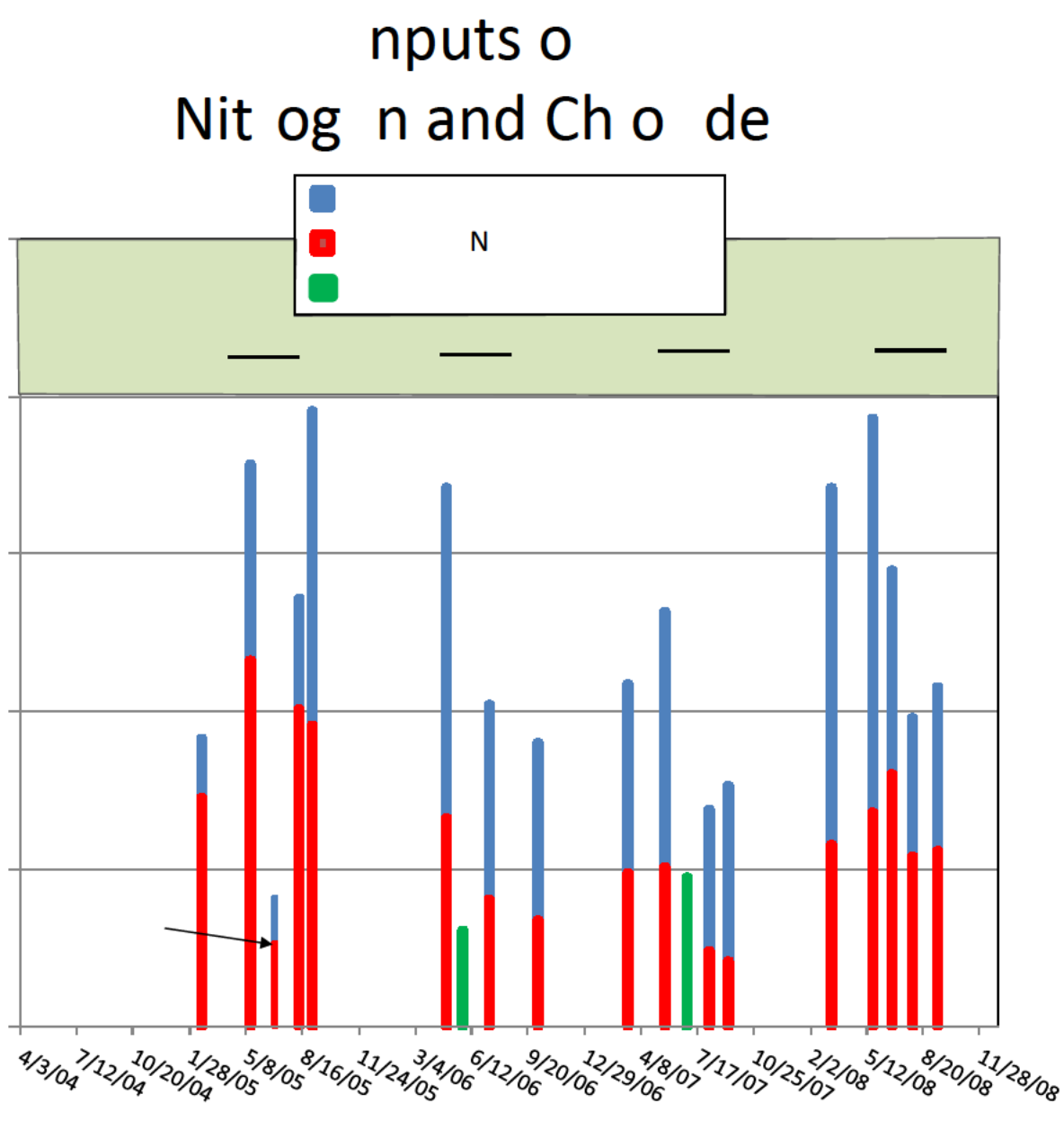


Plate 2 Inputs outputs of nitrogen and so conditions

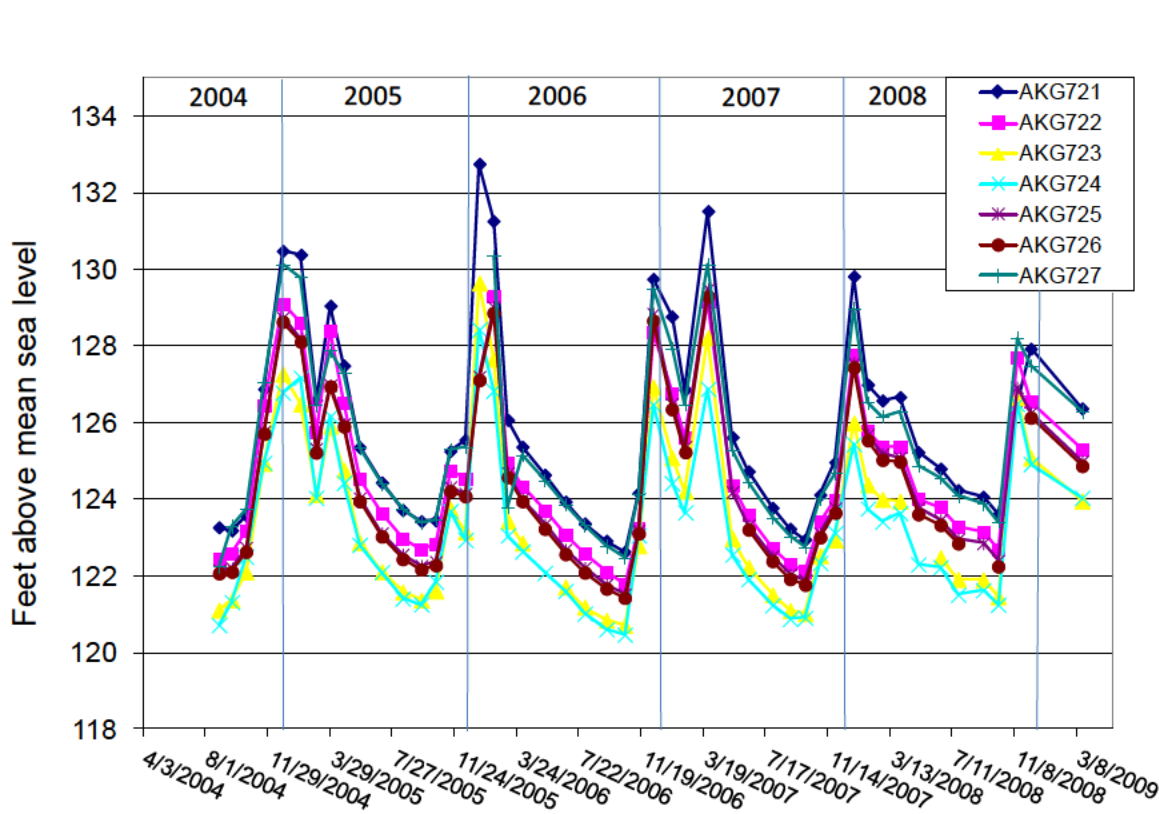


Figure 27. Water table elevations in the monitoring wells relative to the top of casing of AKG721 (134.00 feet, NAVD88).

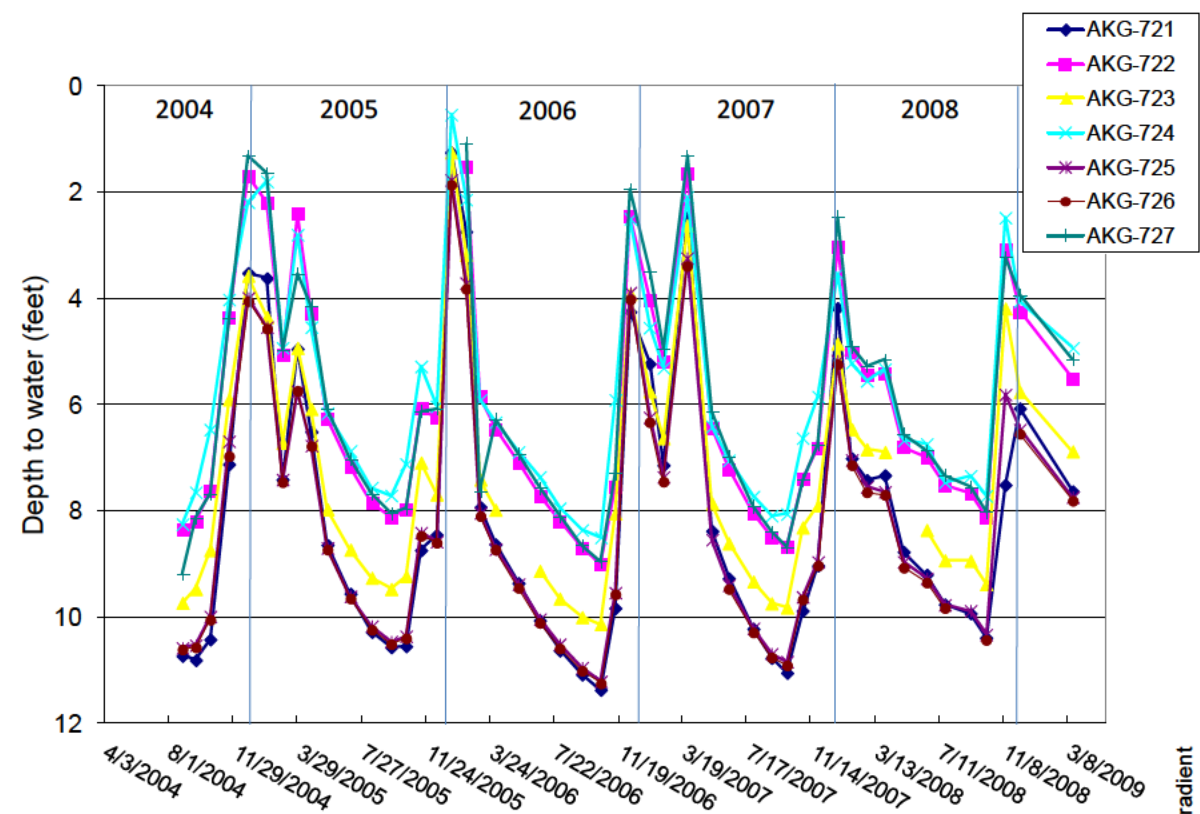


Figure 28. Depth to water from ground surface in the monitoring wells.

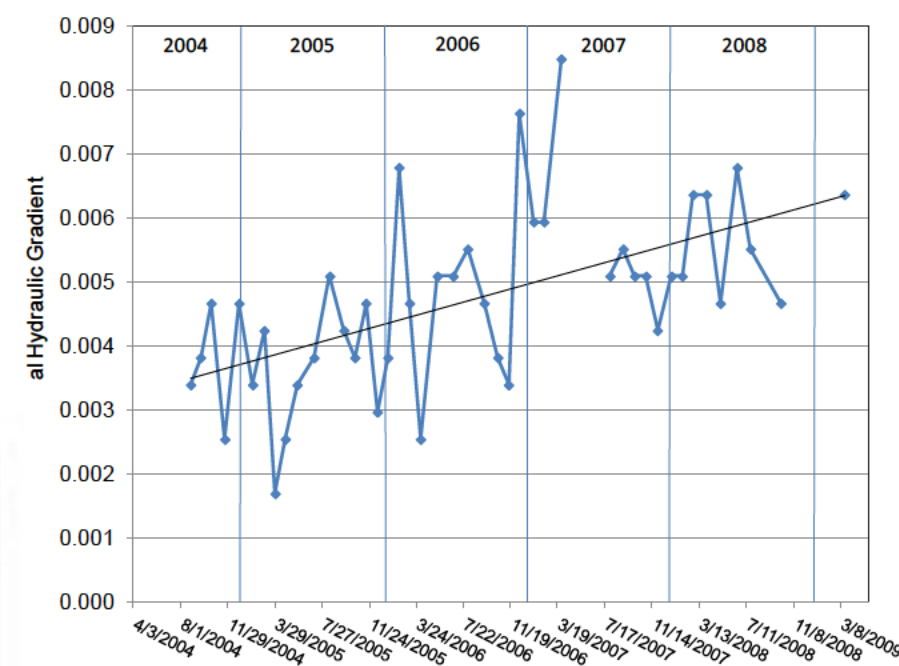


Figure 30. Vertical hydraulic gradient at side-by-side wells, AKG725 (13 feet deep) and AKG726 (38 feet deep).

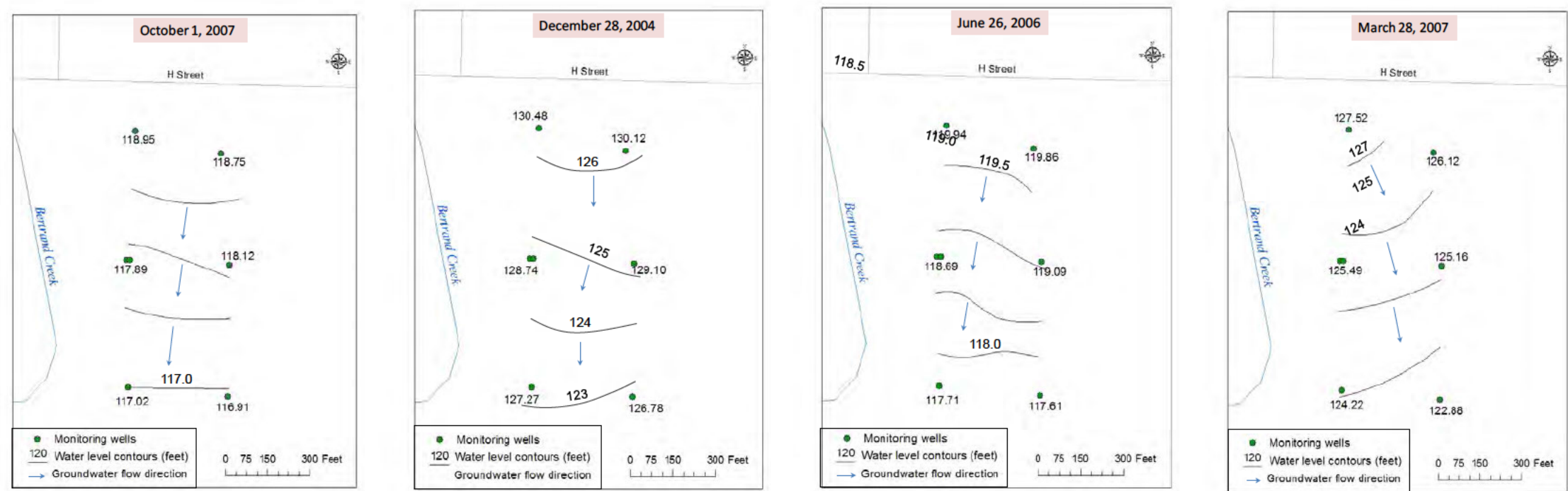
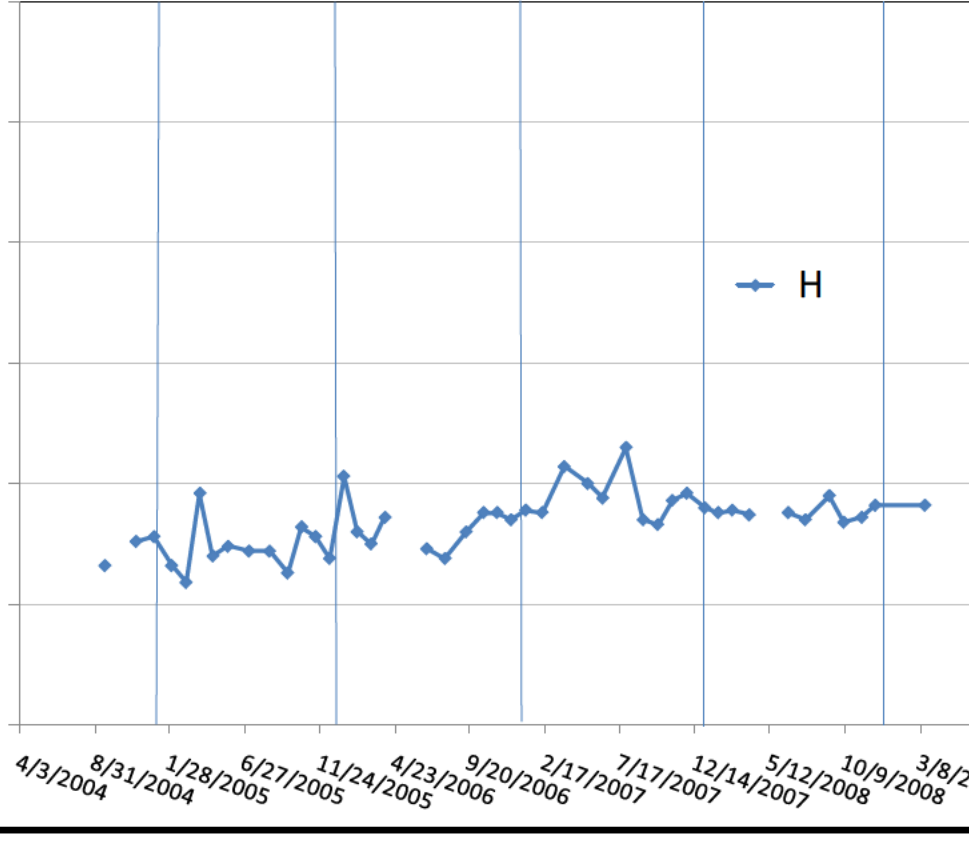
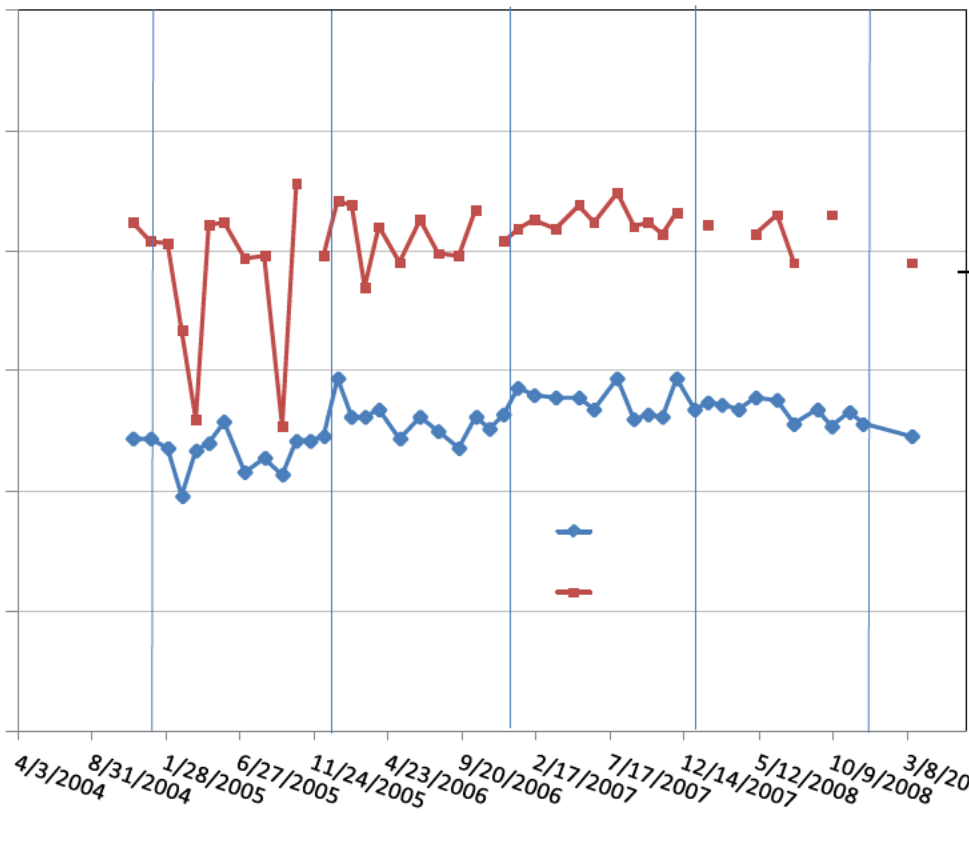
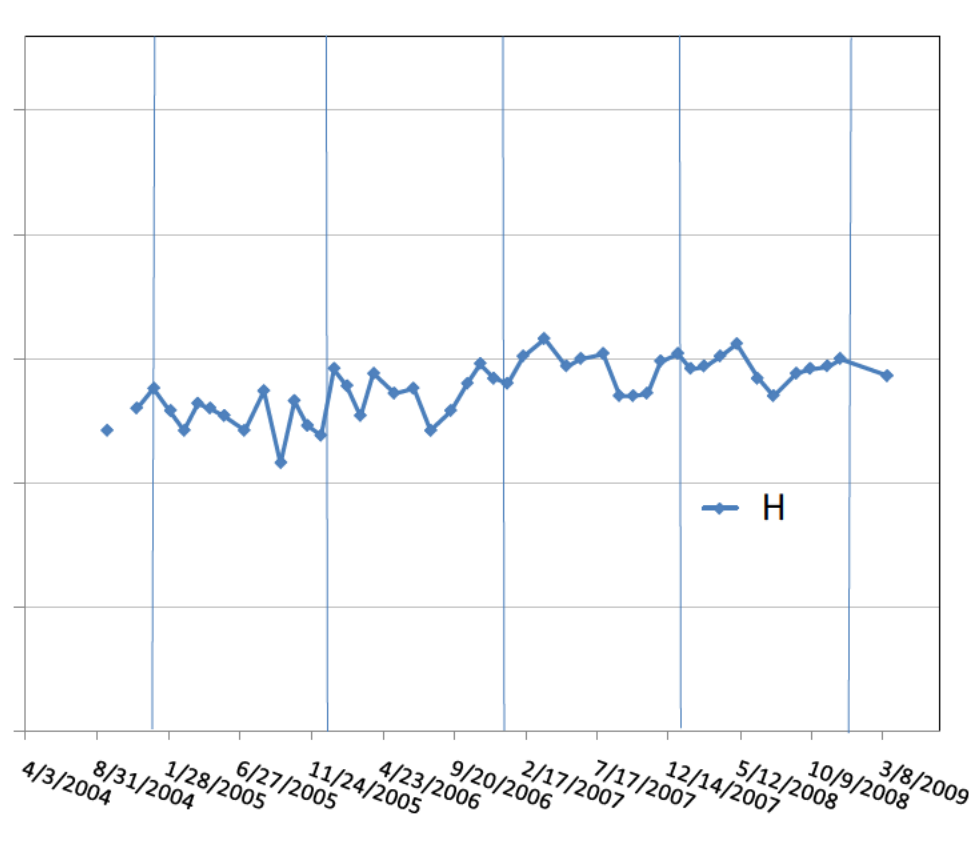
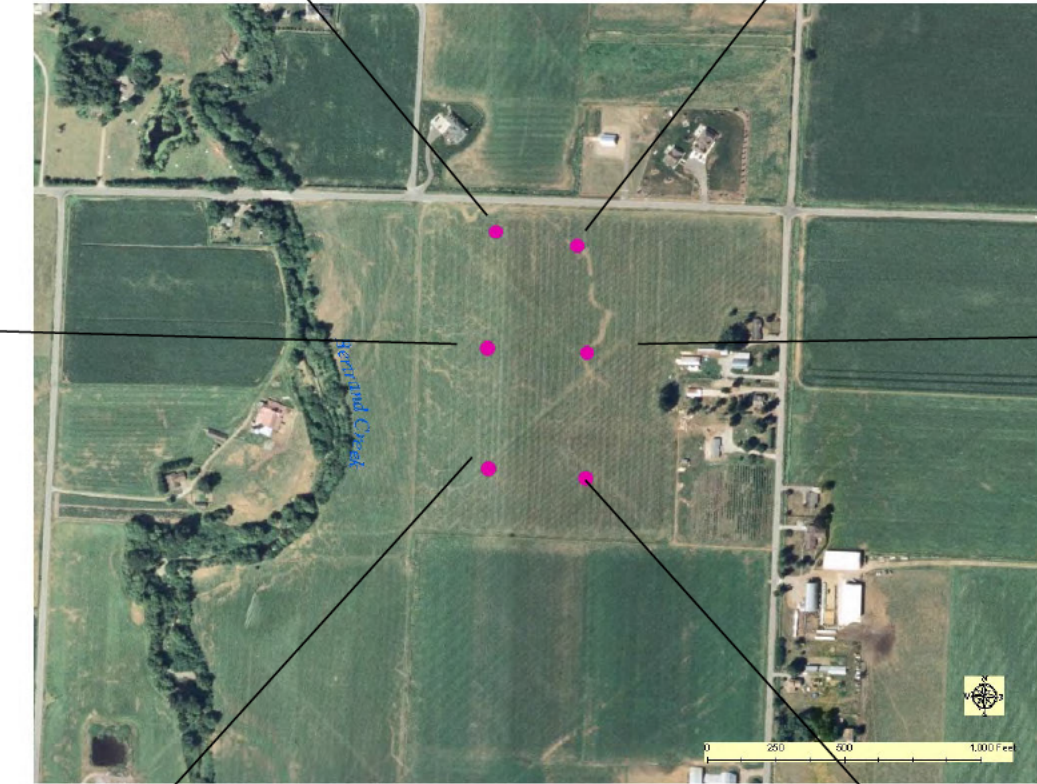
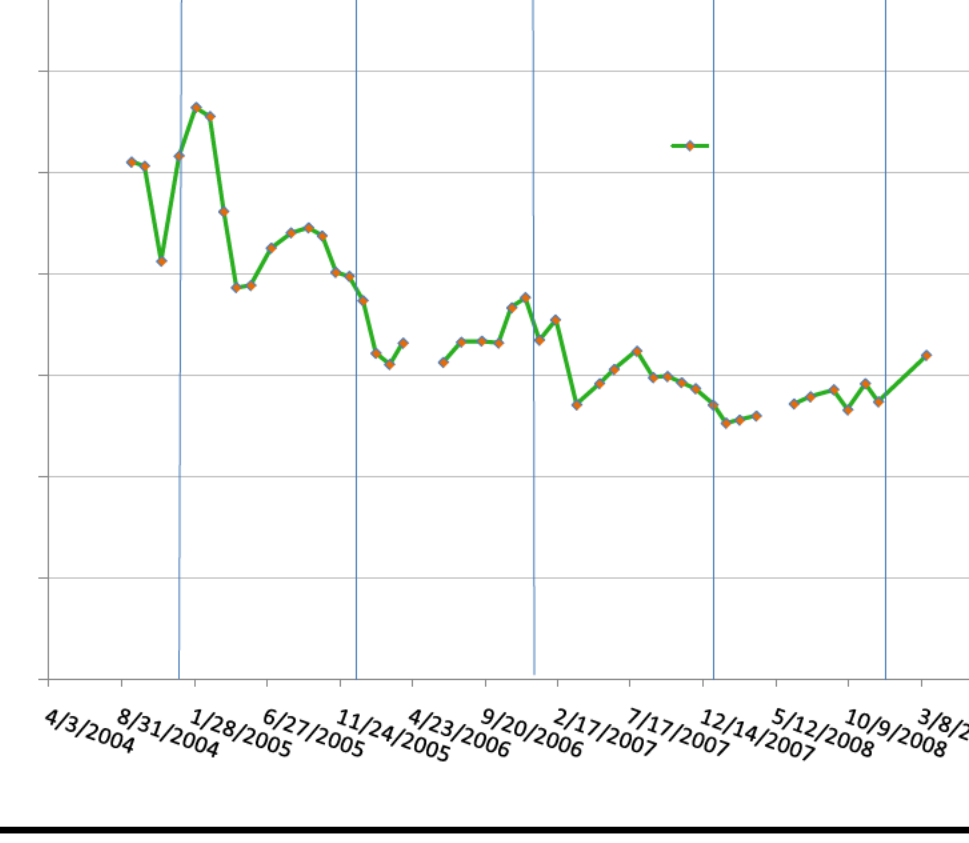
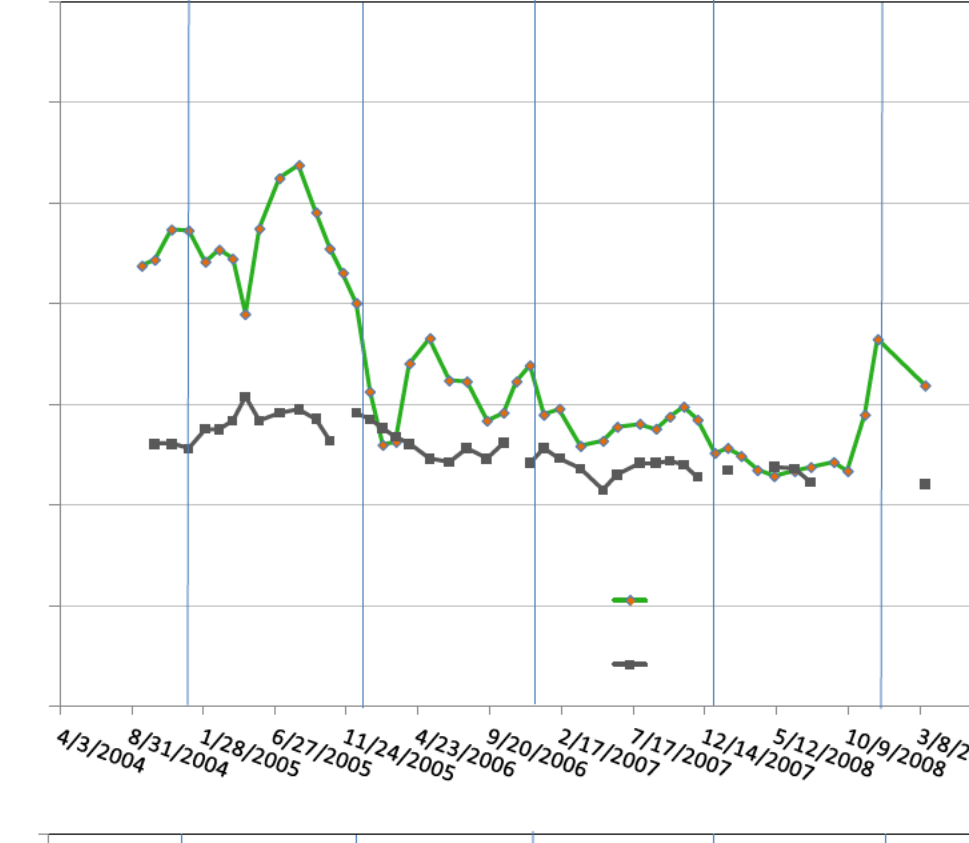
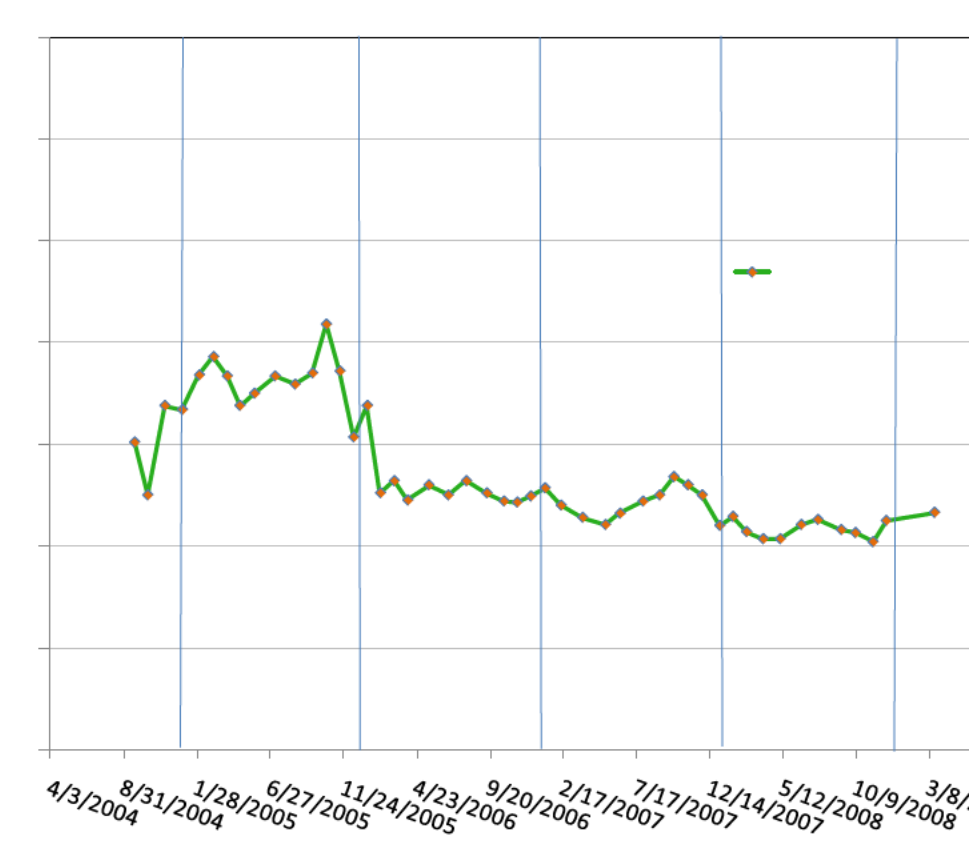
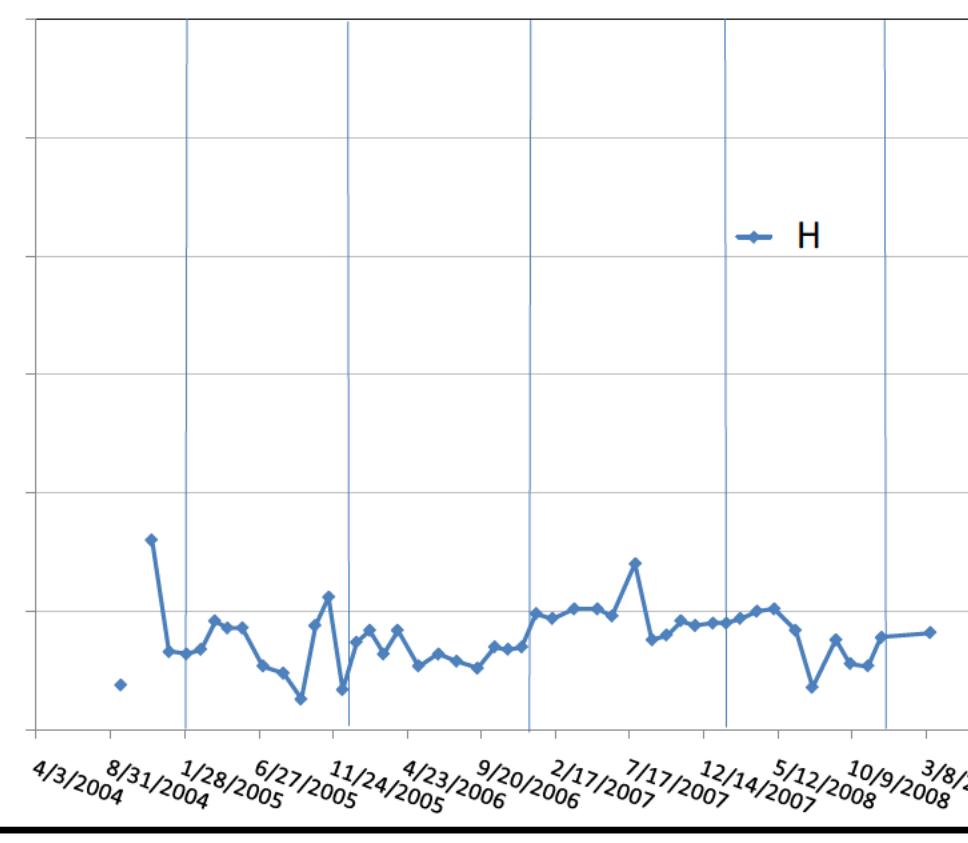
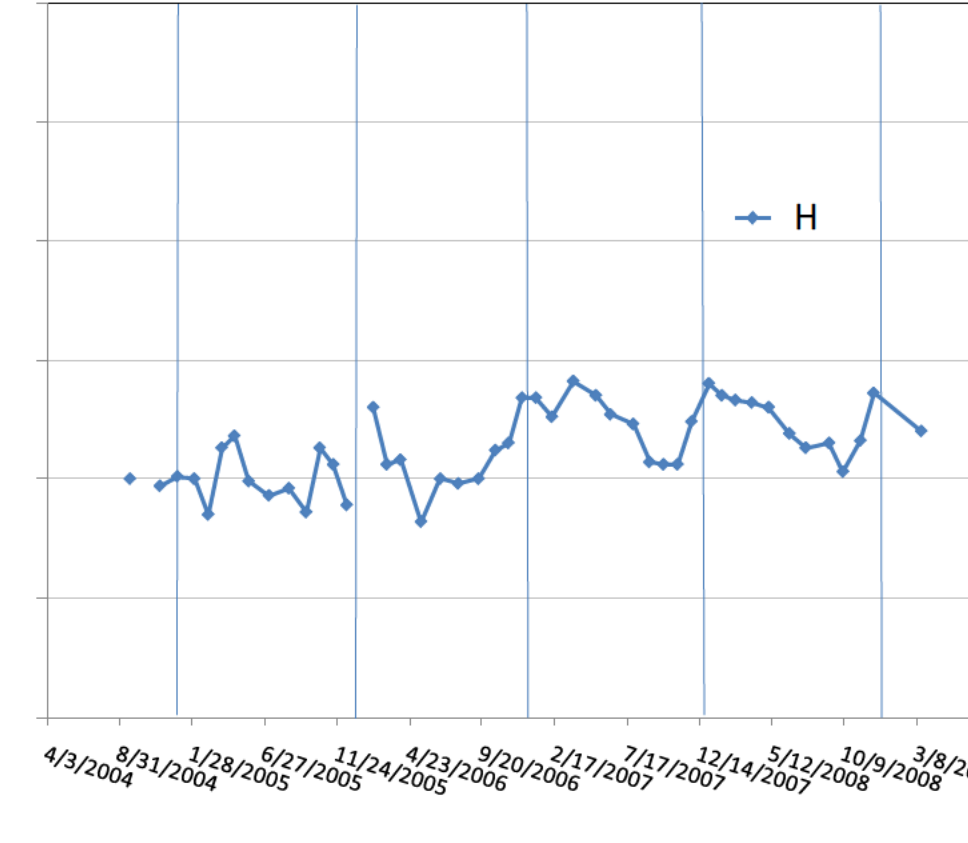
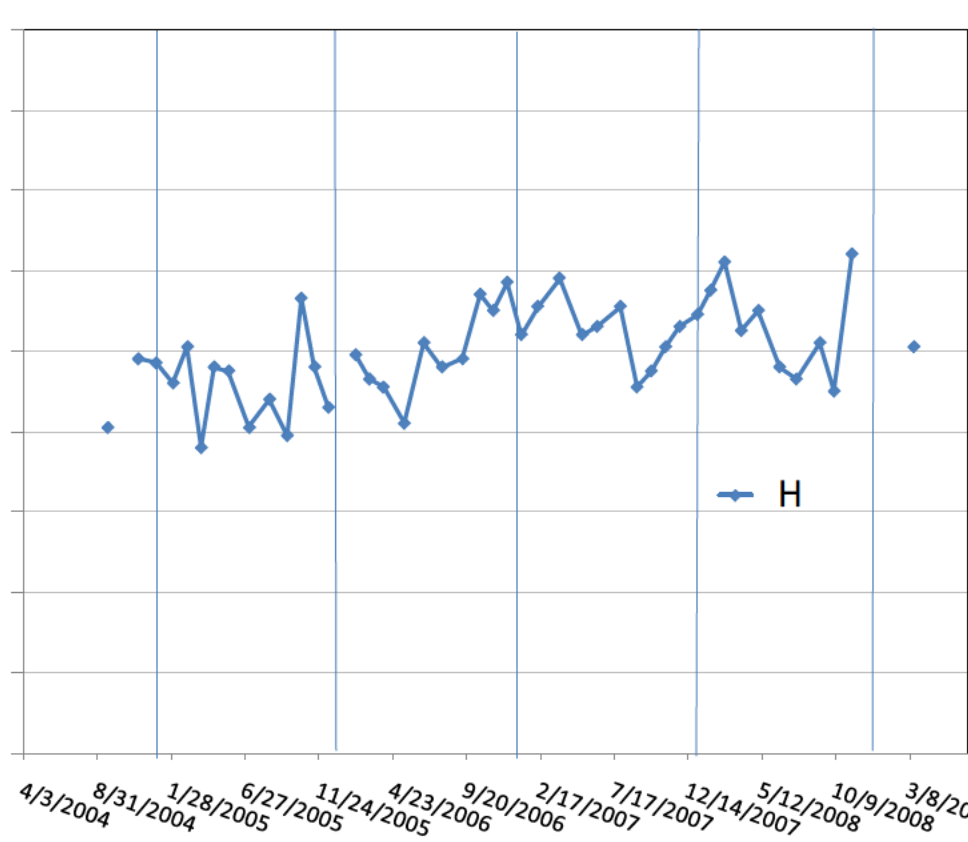


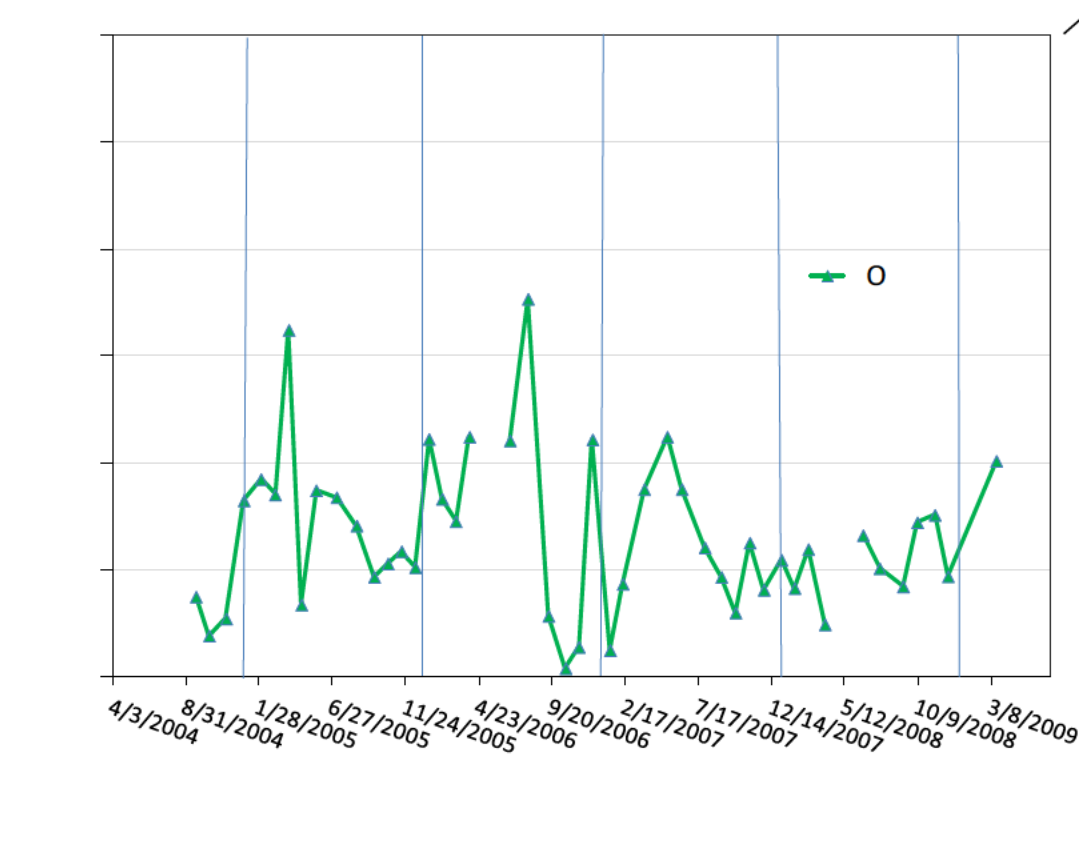
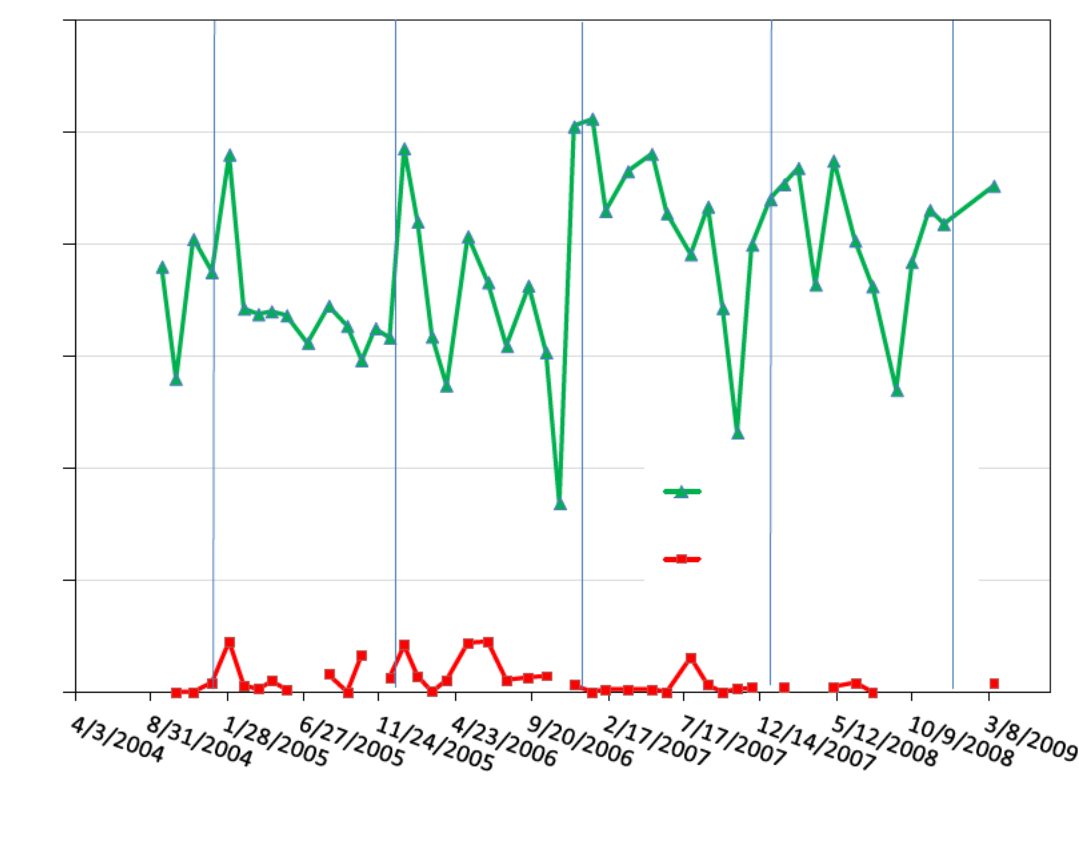
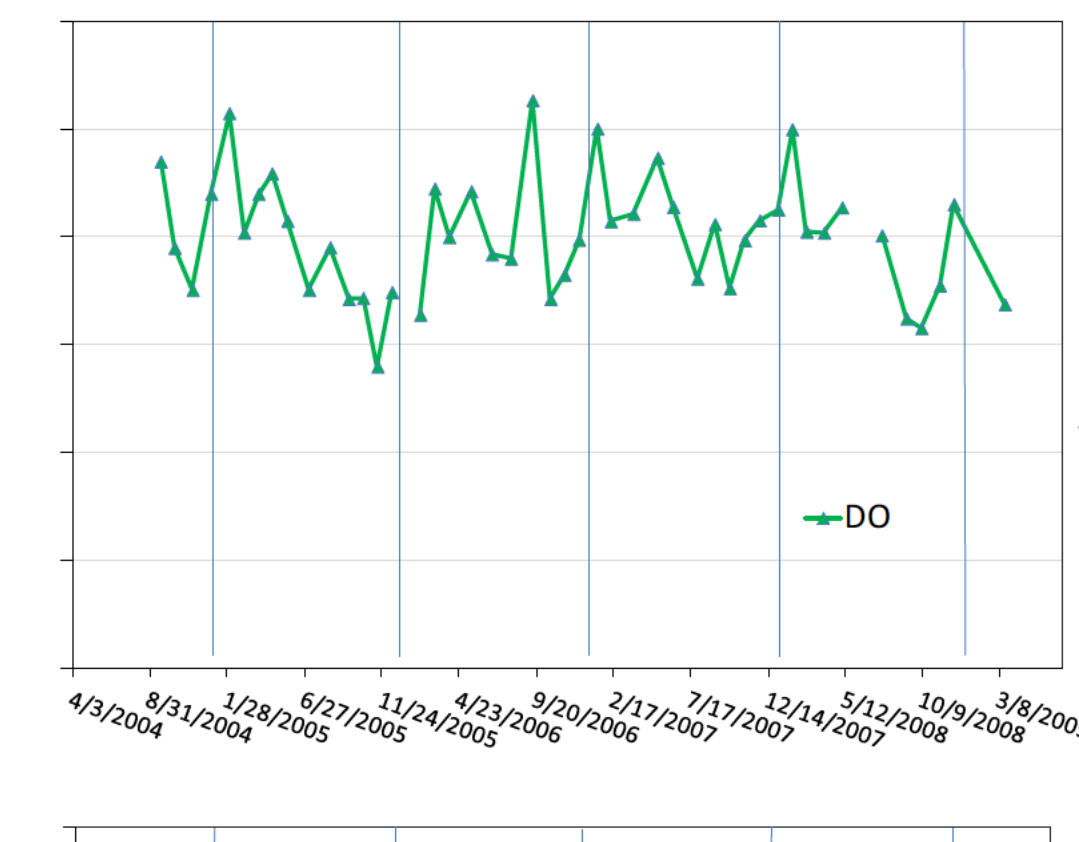
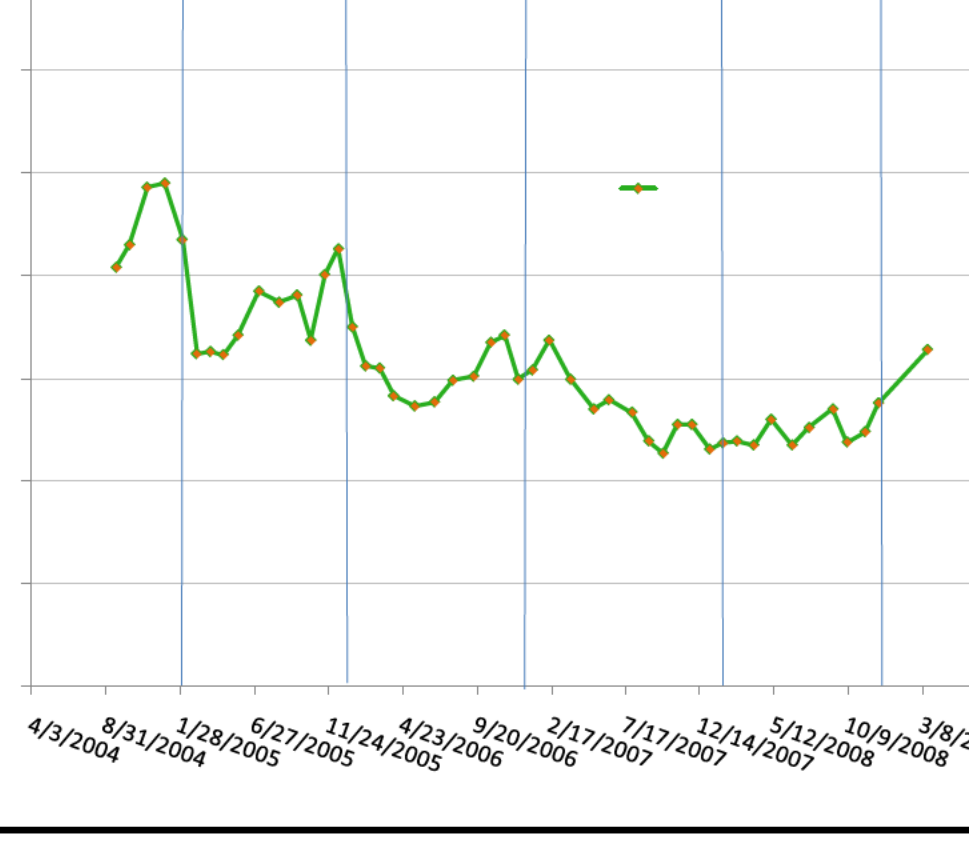
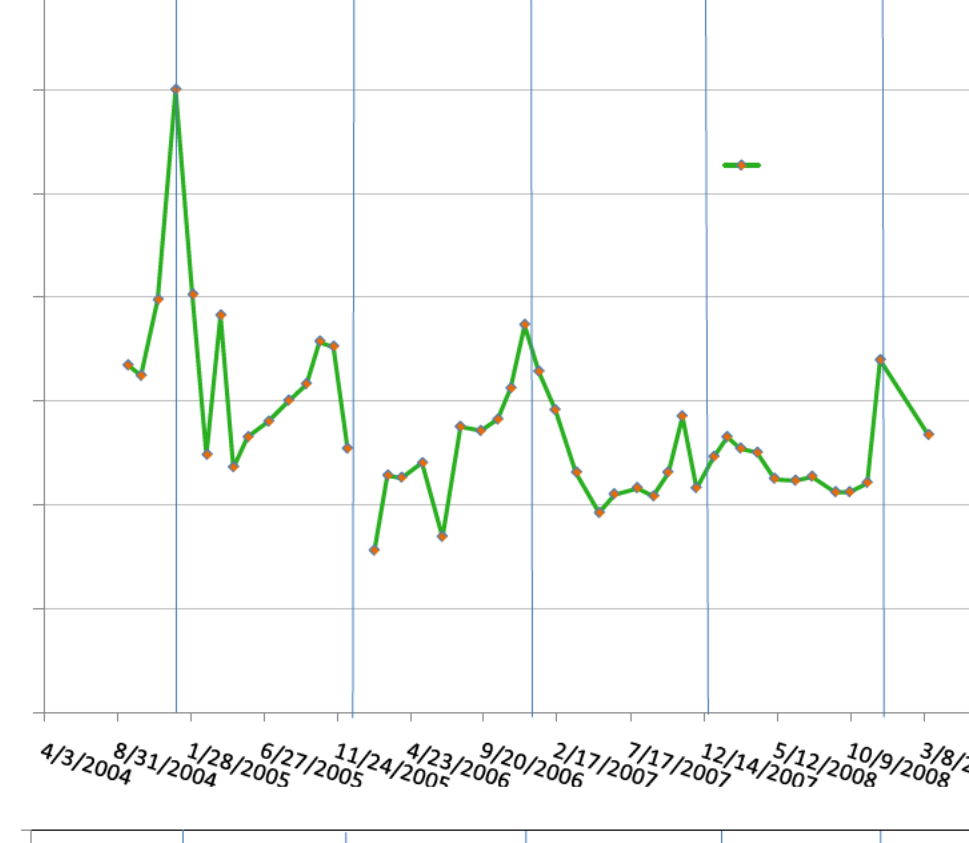
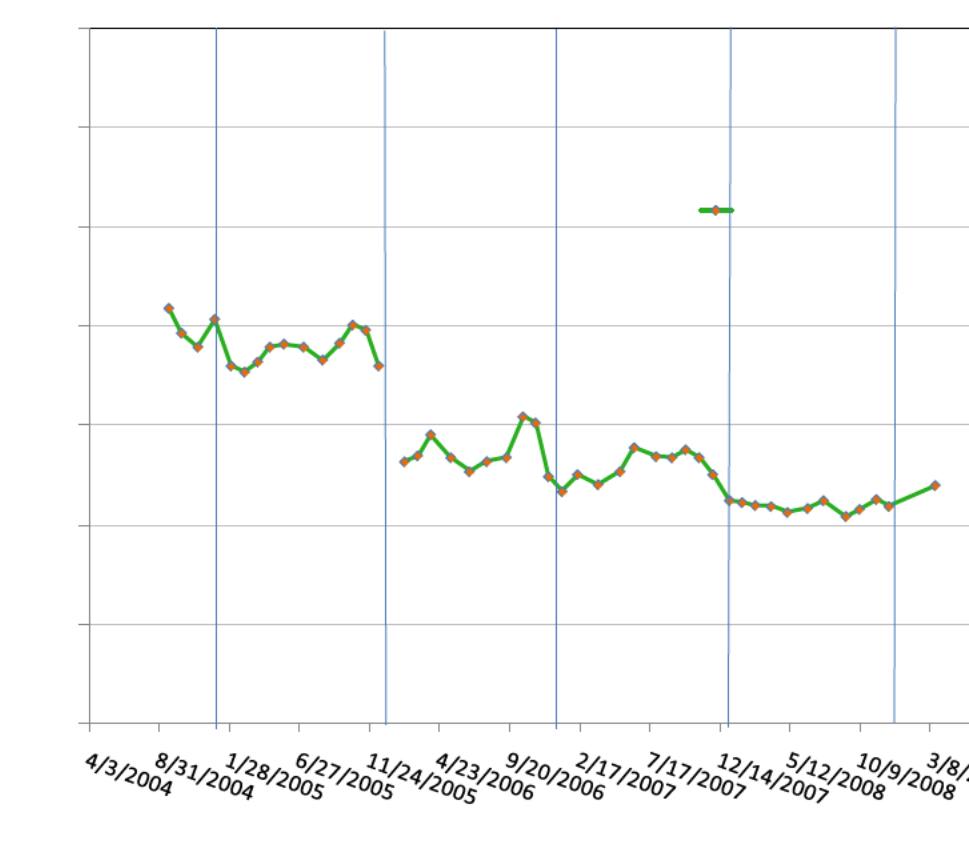
Figure 29. Water level contours in feet based on depth-to-water measurements on December 28, 2004 (winter), June 26, 2006 (summer), October 1, 2007 (fall), and March 28, 2007 (spring). Elevations are relative to the top of casing at AKG721 (134.00 feet, NAVD88)



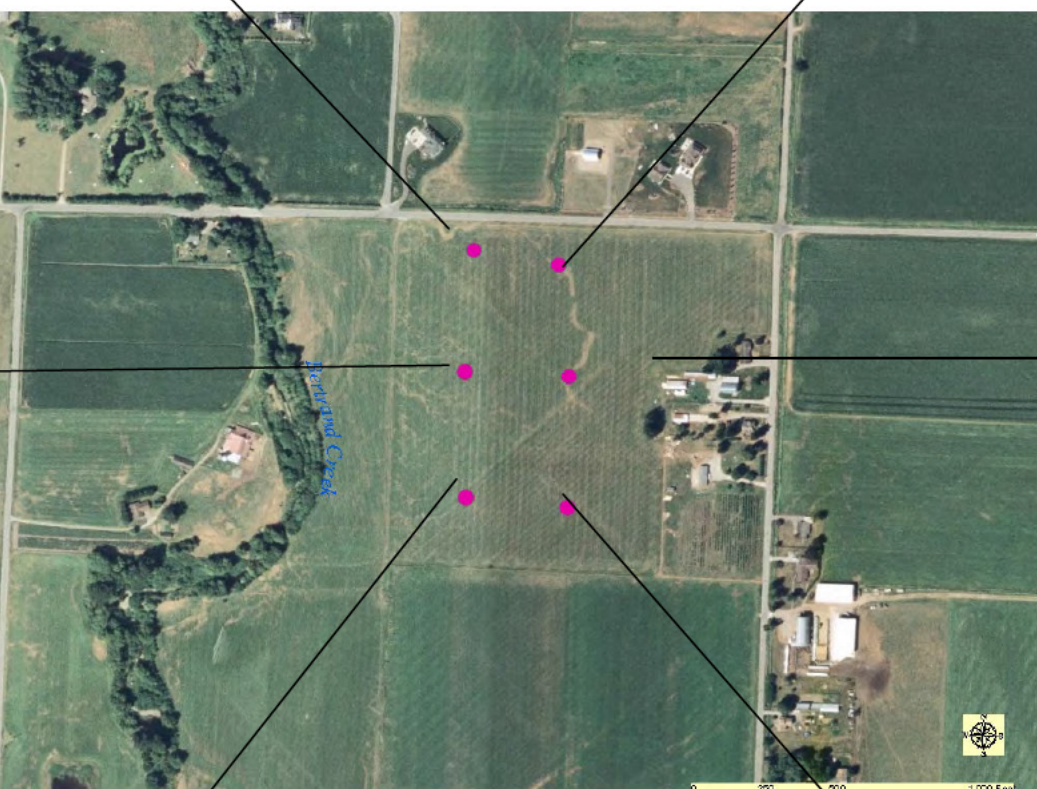
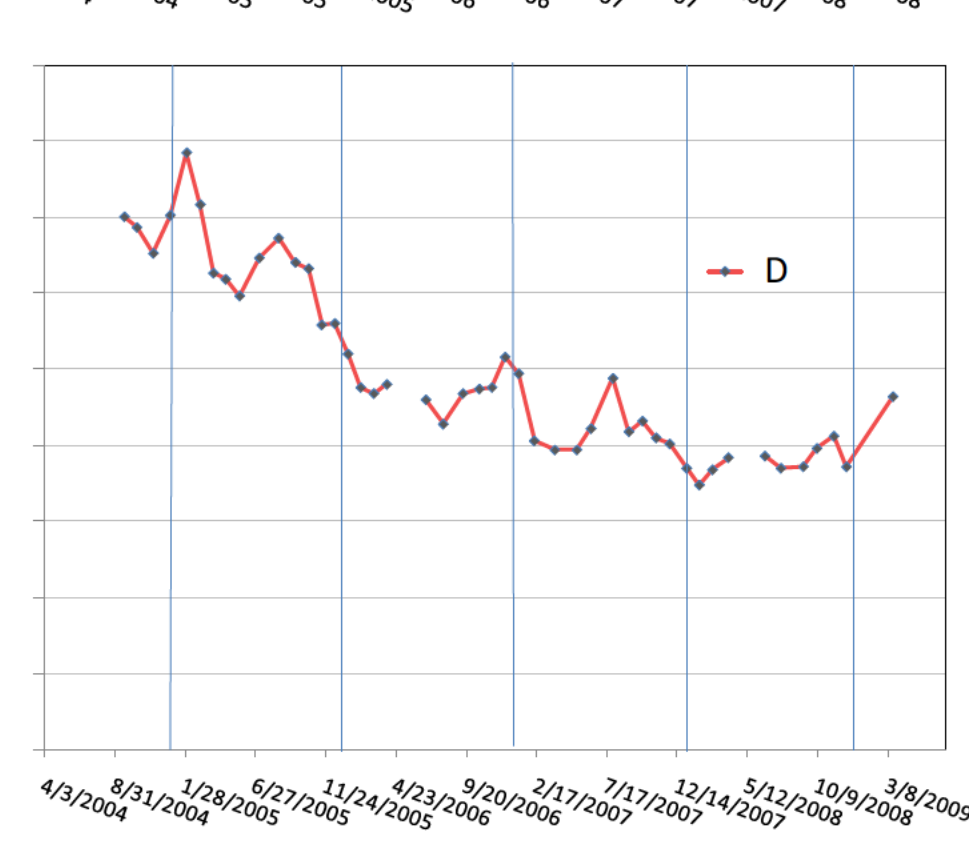
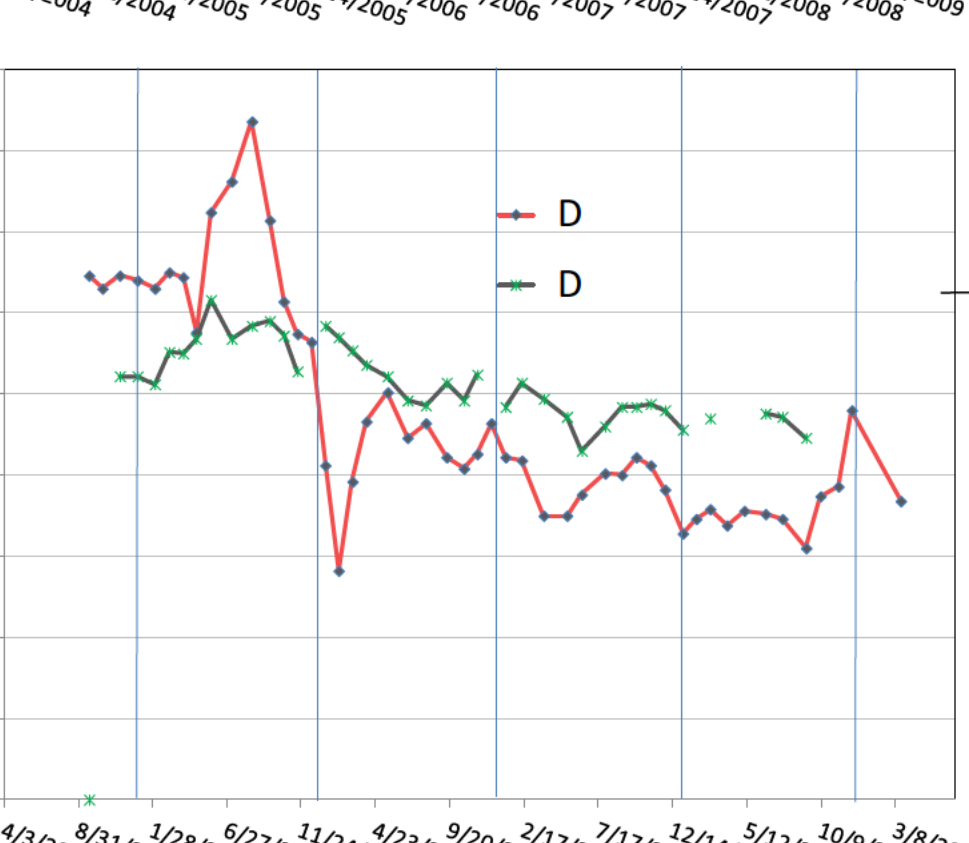
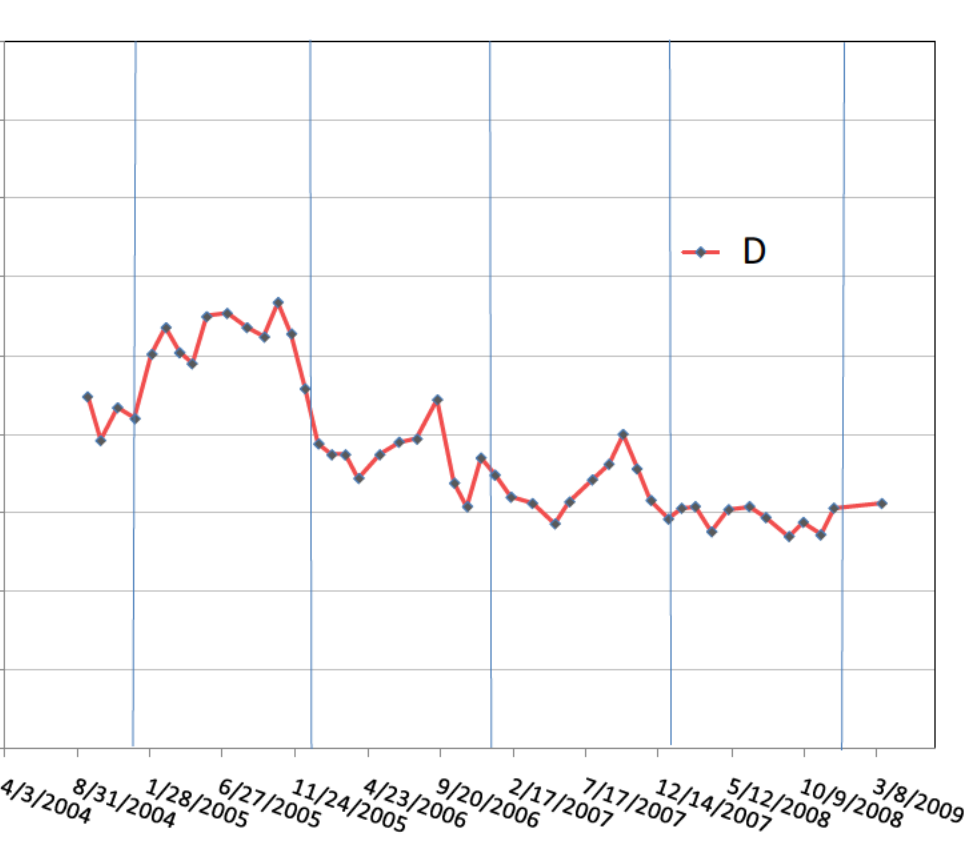
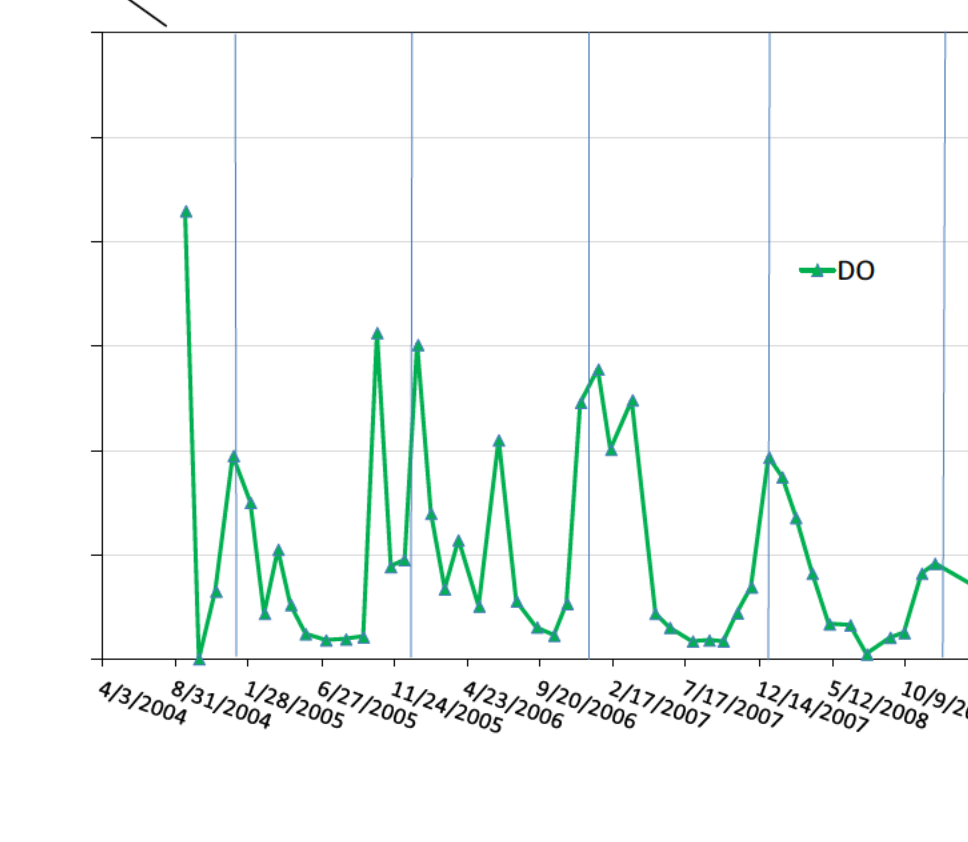
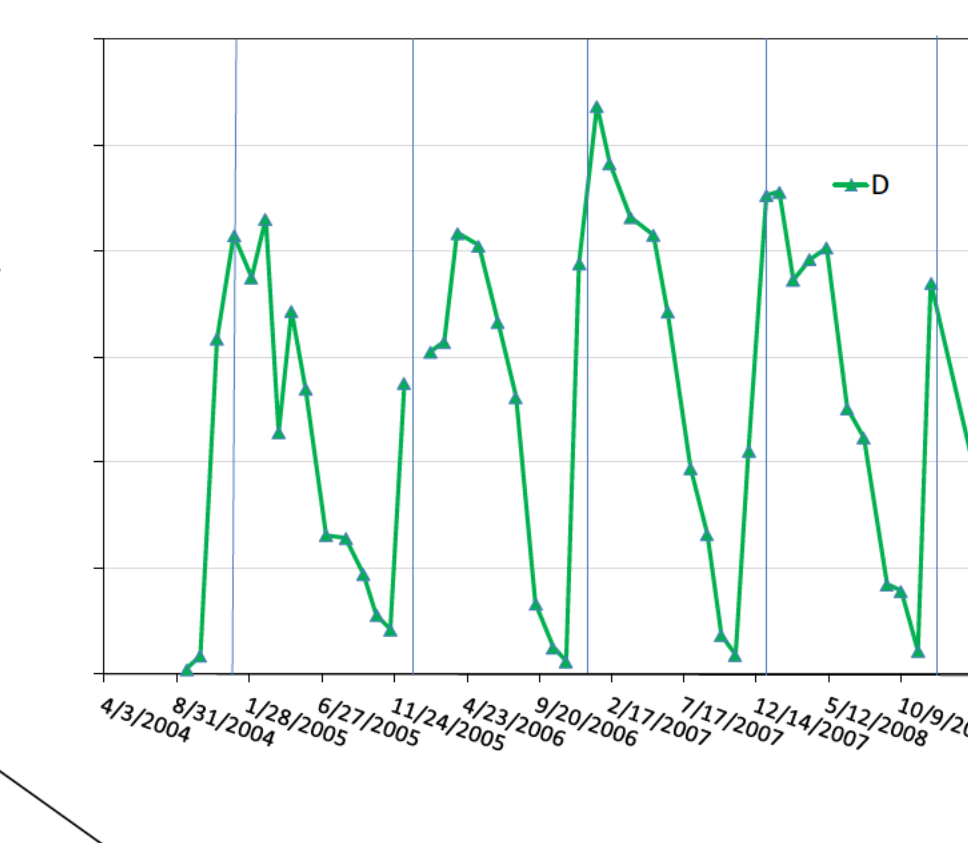
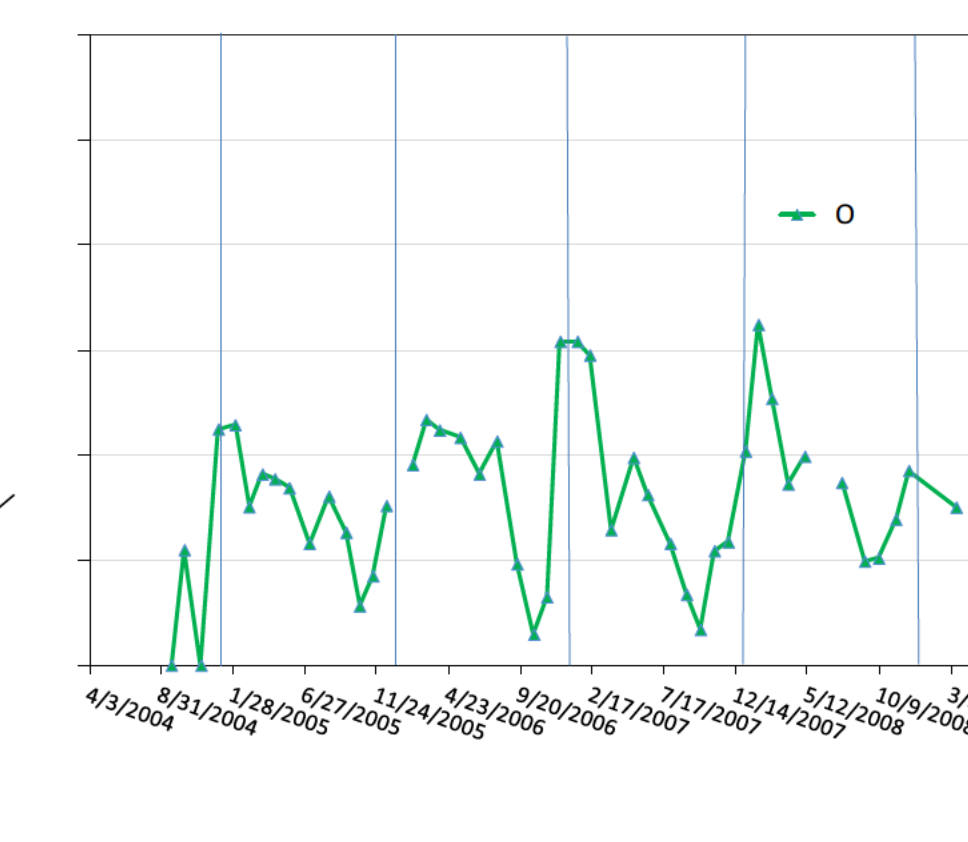
gu e 2 pH va u s in g oundw te



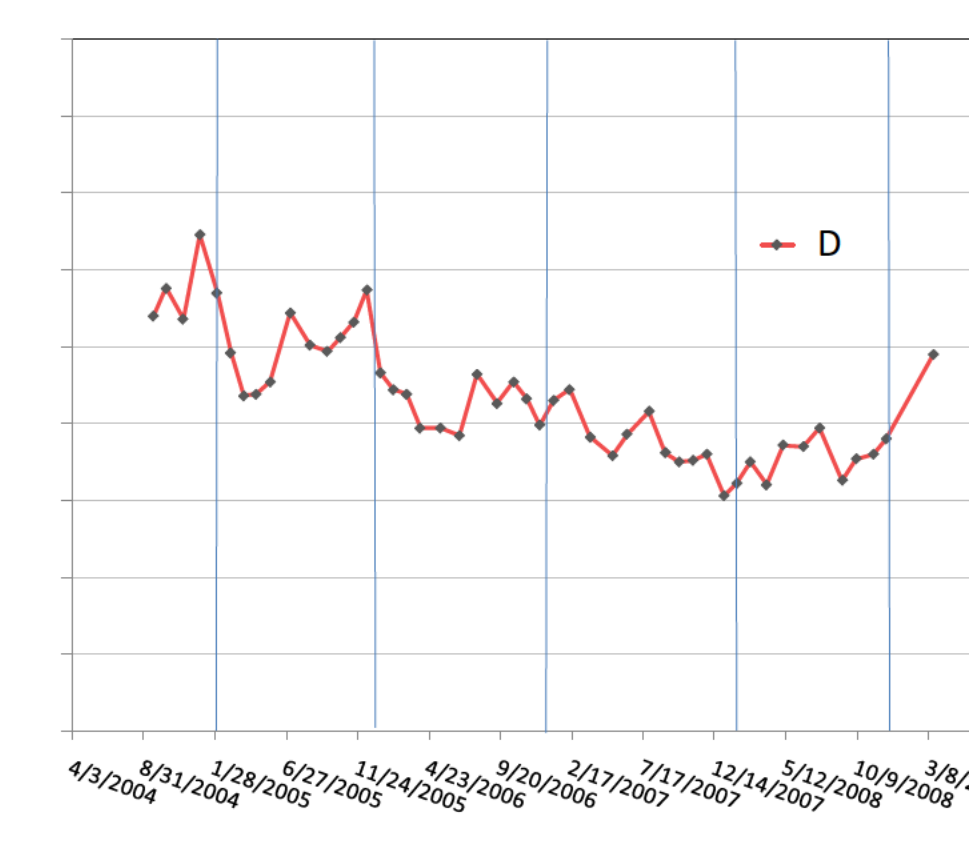
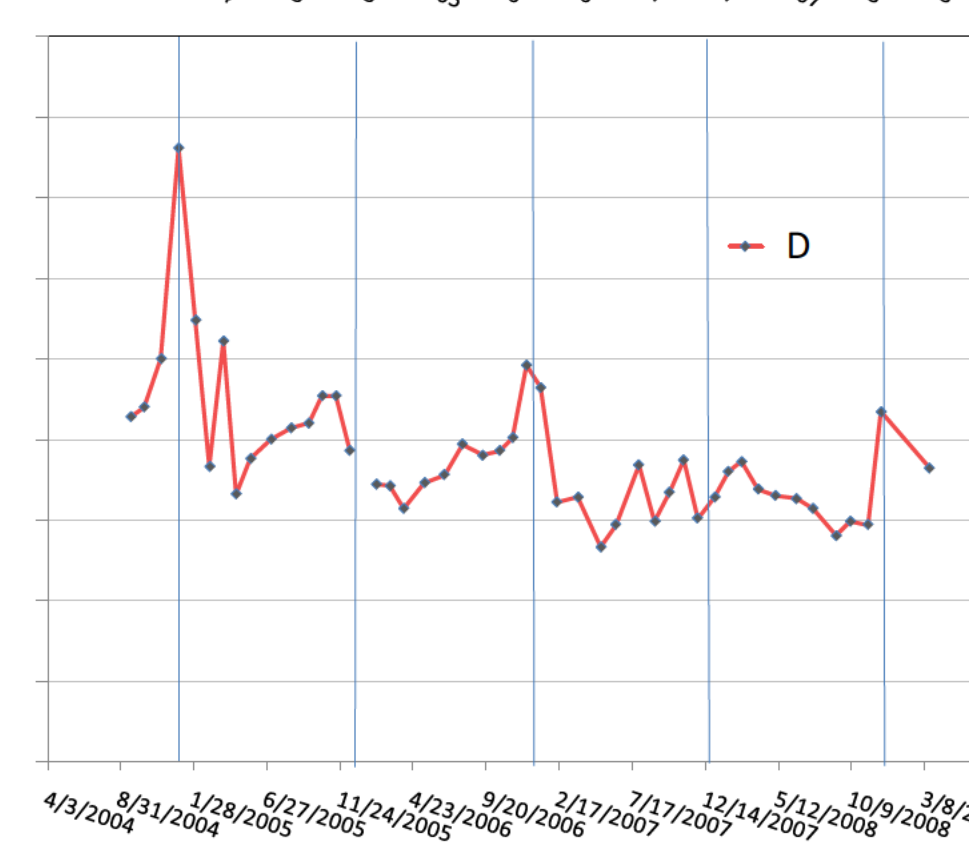
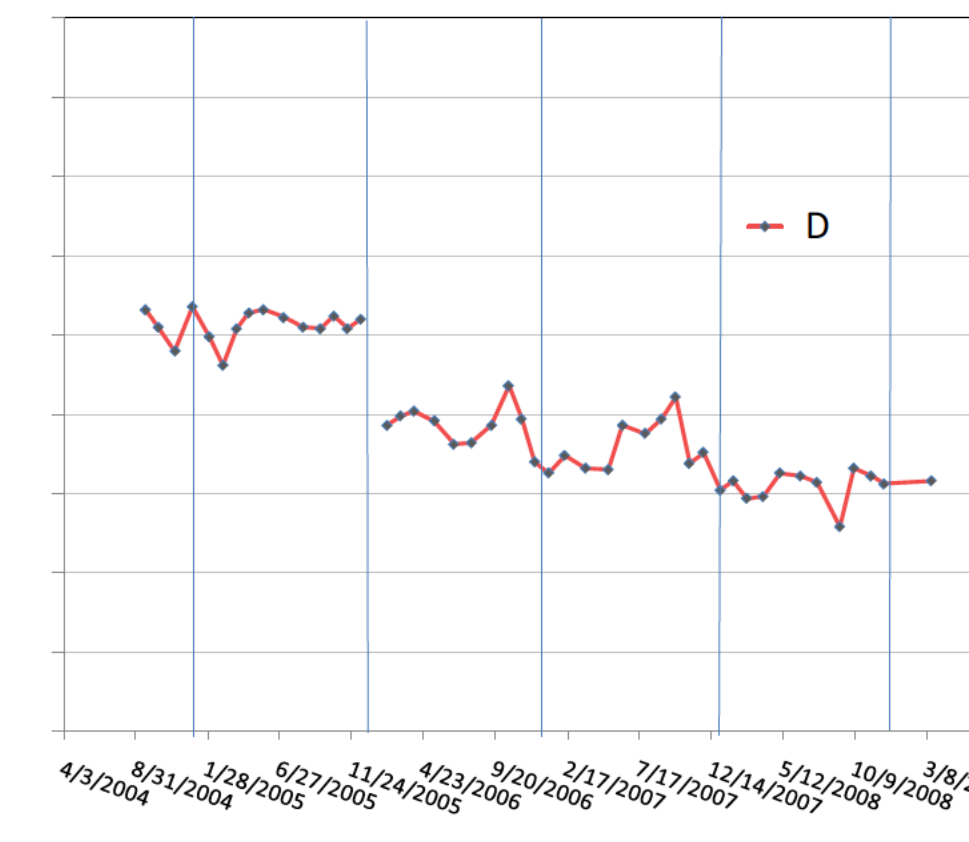
i u e 34 Spe i c con uc an e
es l s ng o ndwa e



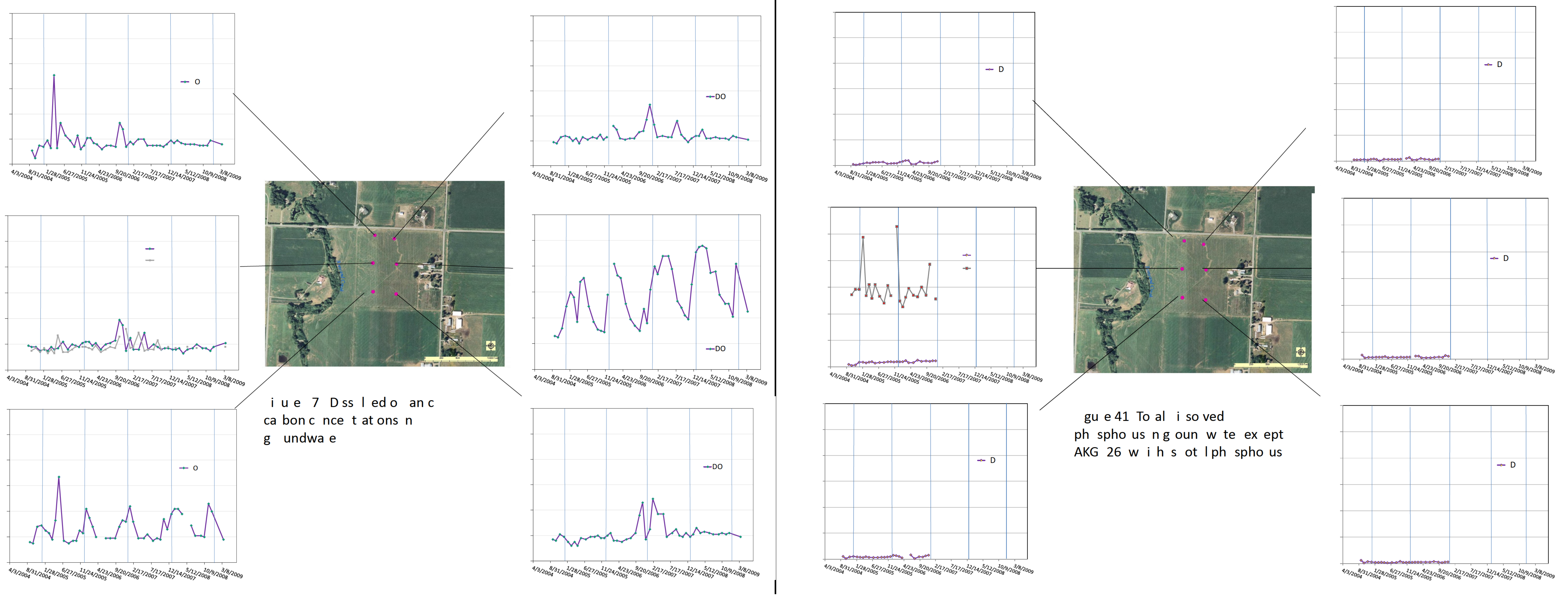
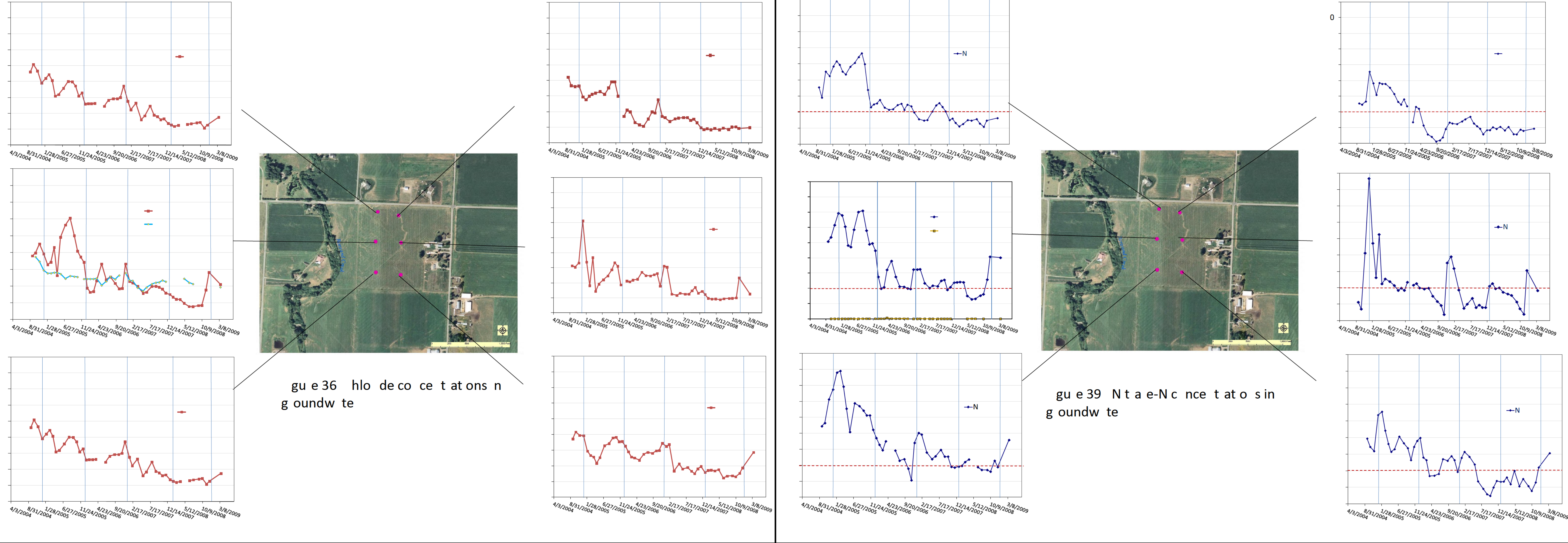
gu e 33 D s ol ed o ygen
co cent t ons n g oundw te



gu e 35 DS con ent a ons
n g o ndwa e



P te 4 pH d sso ved oxygen (DO) conduct v ty and to a d so ved so ds (TDS) concent at ons n g oundw te



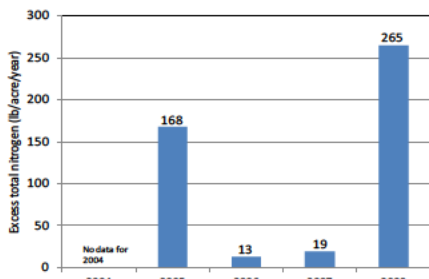


Figure 44. Mass balance estimates of annual excess nitrogen in lb/acre.

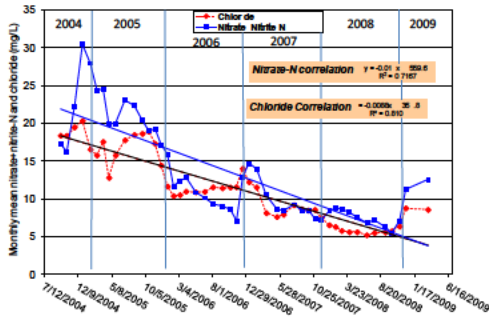


Figure 46. Mean shallow groundwater nitrate-N and chloride concentrations correlated with time.

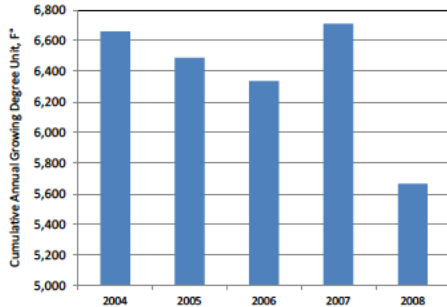


Figure 47. Annual total growing degree days from VanWieringen and Harrison, (2009).

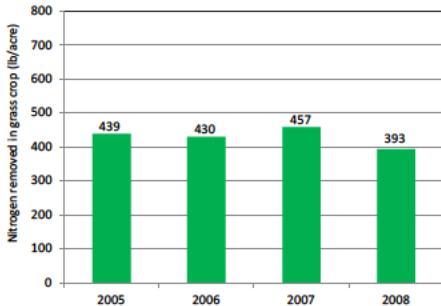


Figure 48. Annual nitrogen removed in the grass crop.

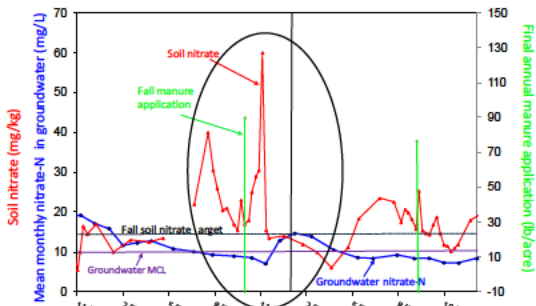


Figure 49. Soil nitrate results and mean shallow groundwater nitrate-N concentrations.

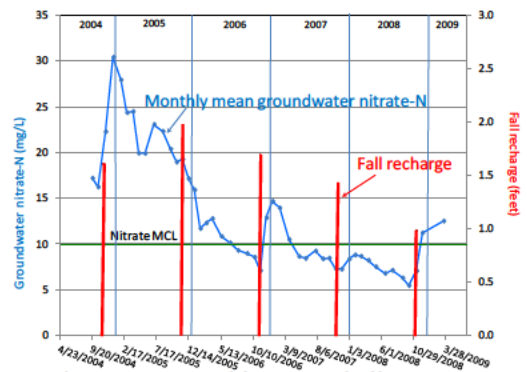


Figure 50. Monthly mean shallow groundwater nitrate-N concentrations and annual fall recharge.

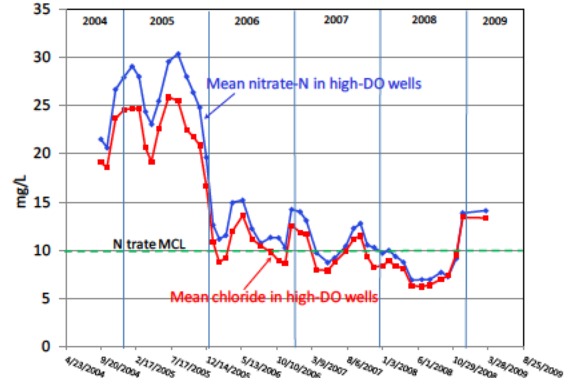


Figure 51. Nitrate-N and chloride concentrations in wells with high D.O.

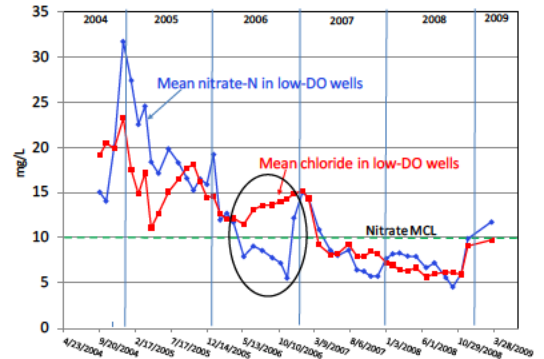


Figure 52. Nitrate-N and chloride concentrations in wells with low D.O. The circle indicates a period when denitrification was probably a strong influence, because DO was less than 2 mg/L and the water table well below the root zone.

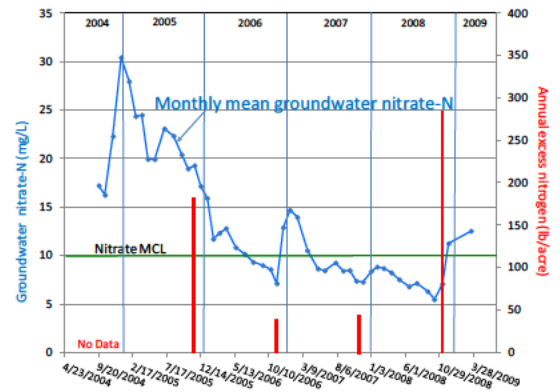
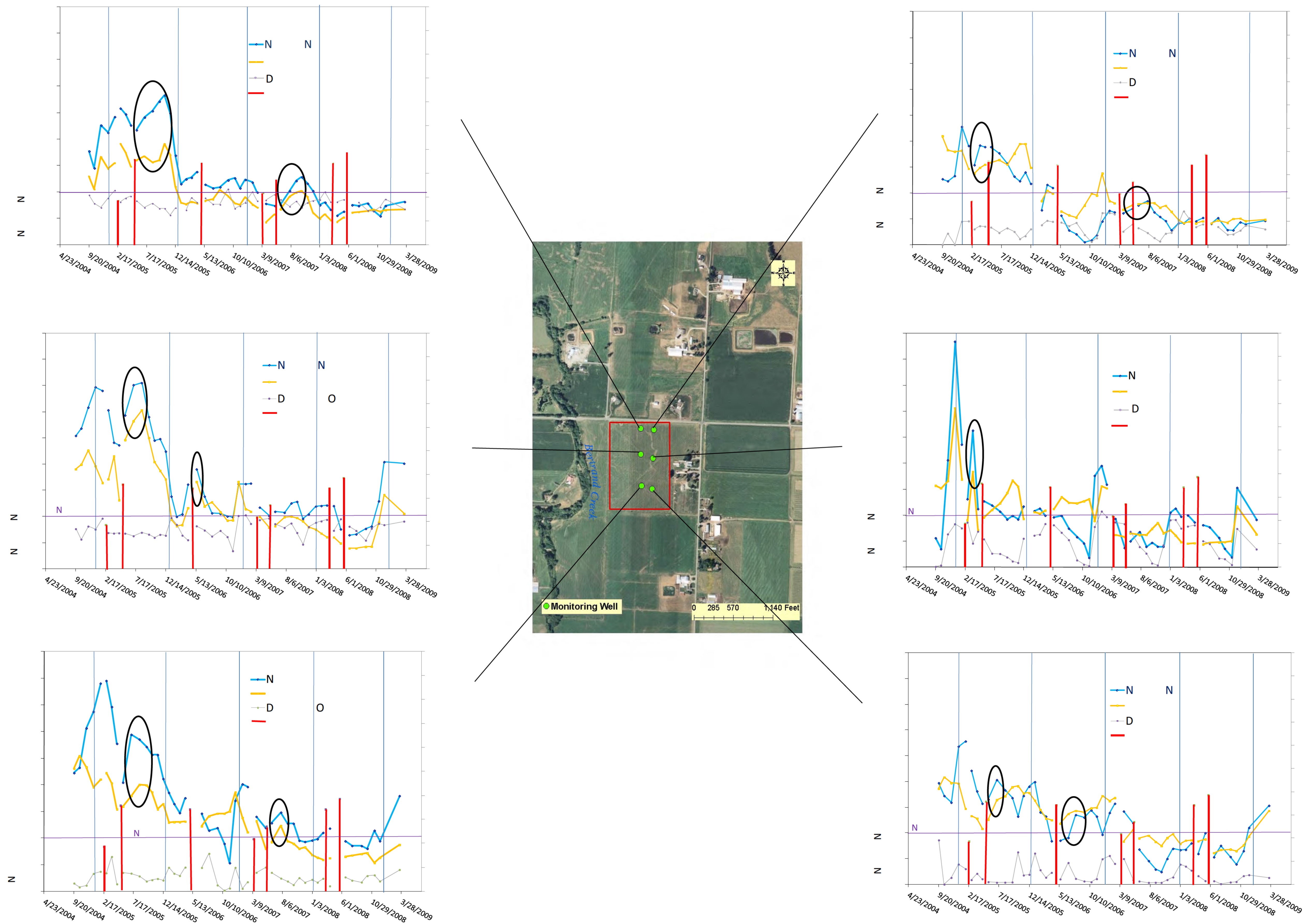
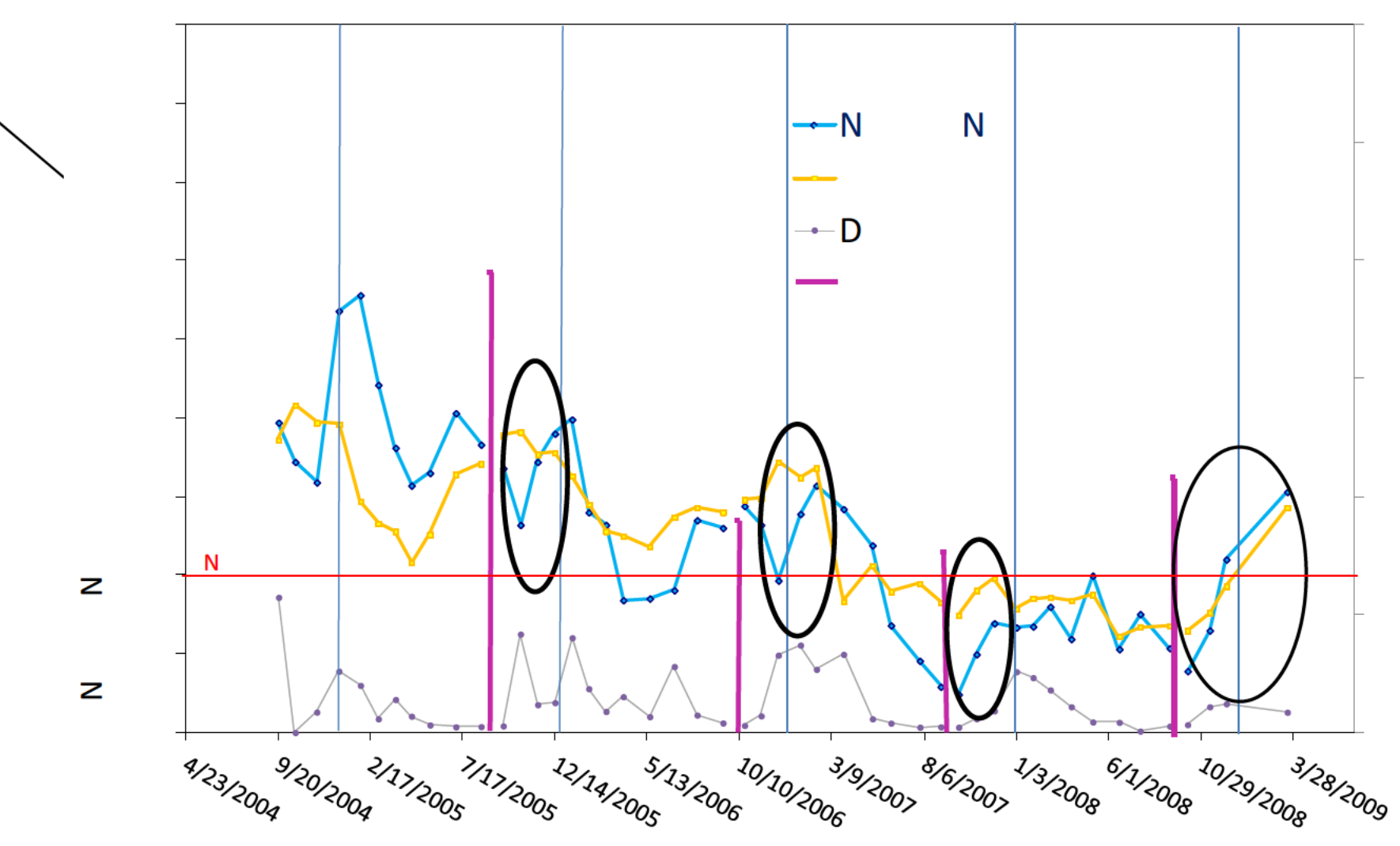
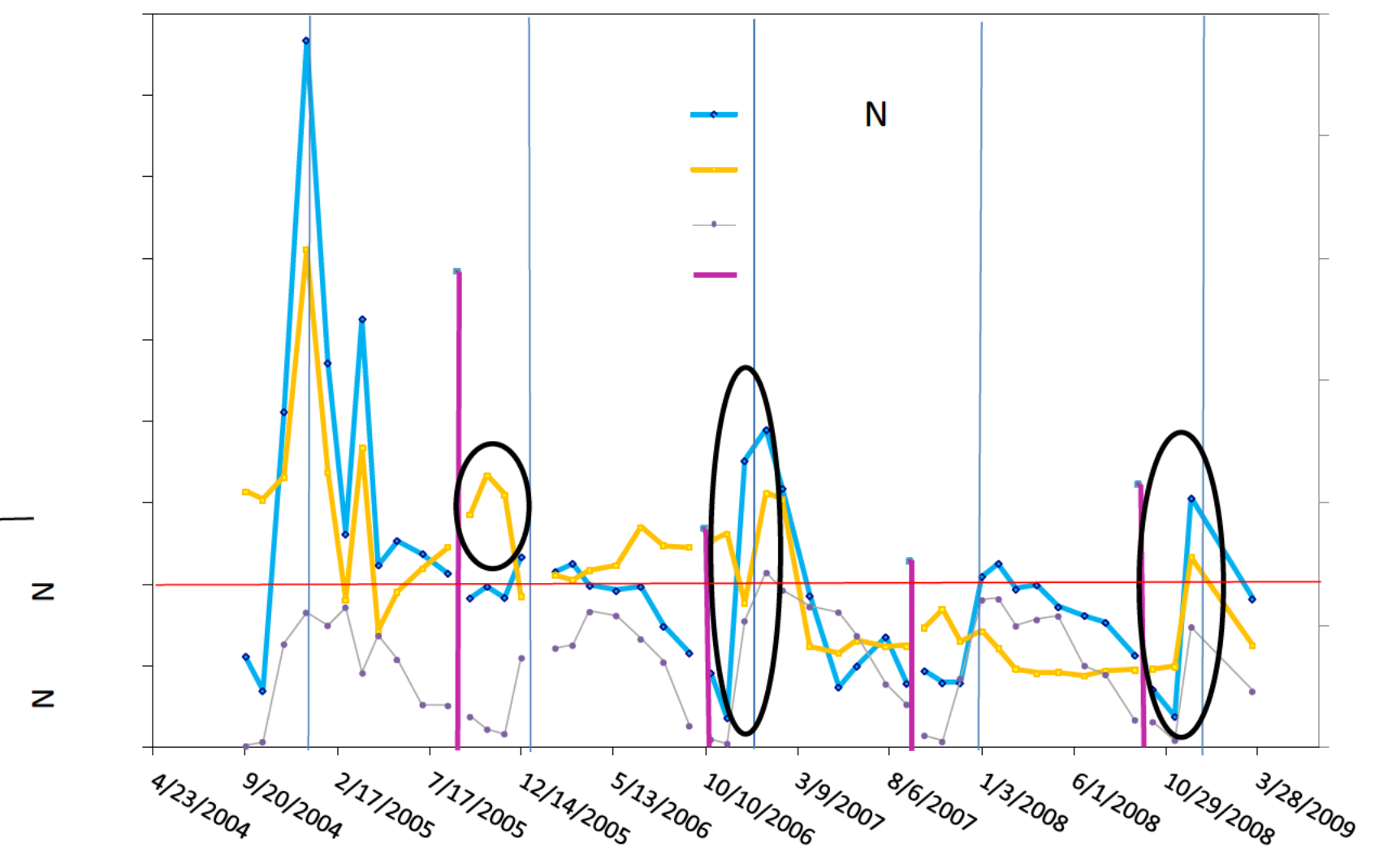
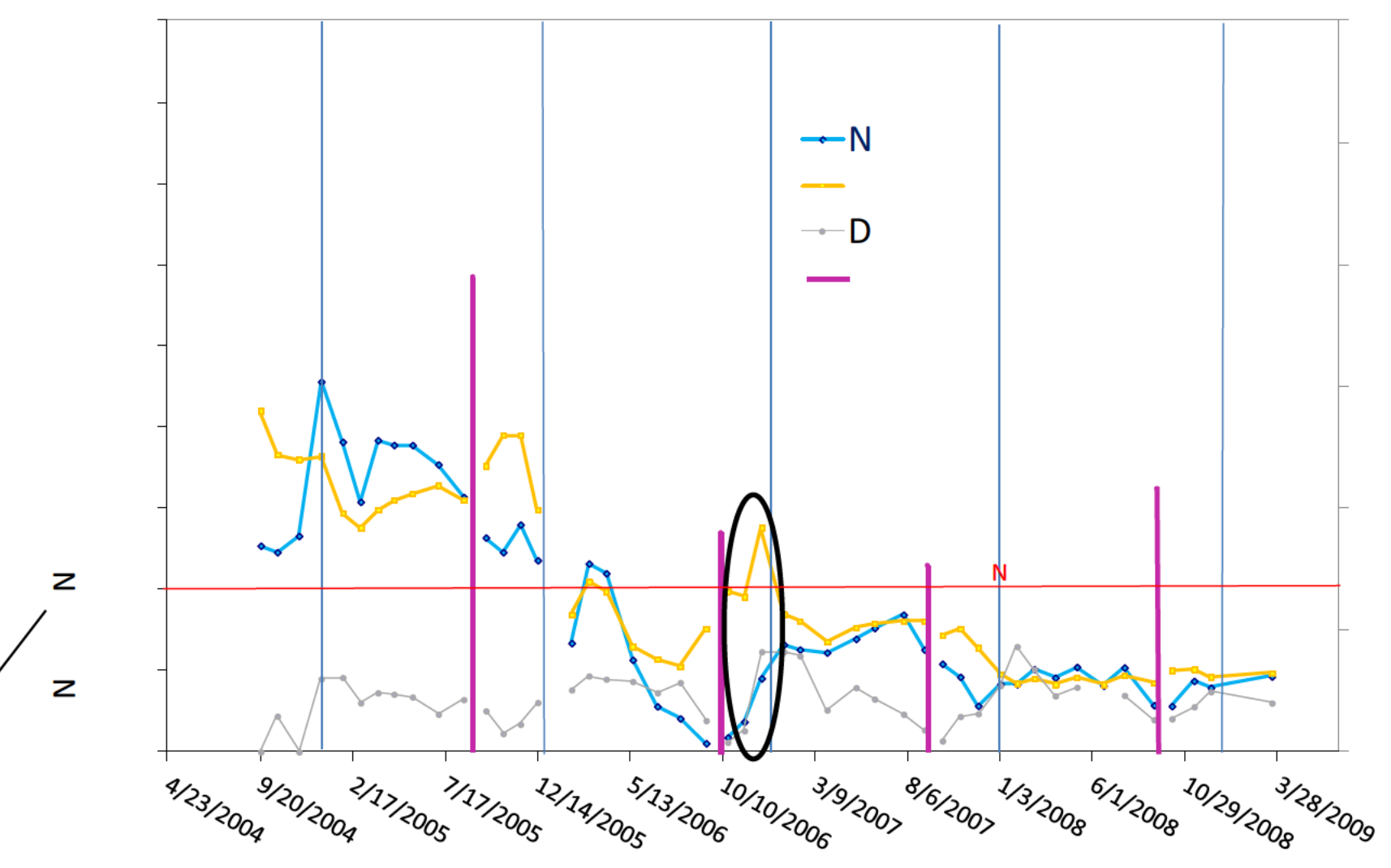
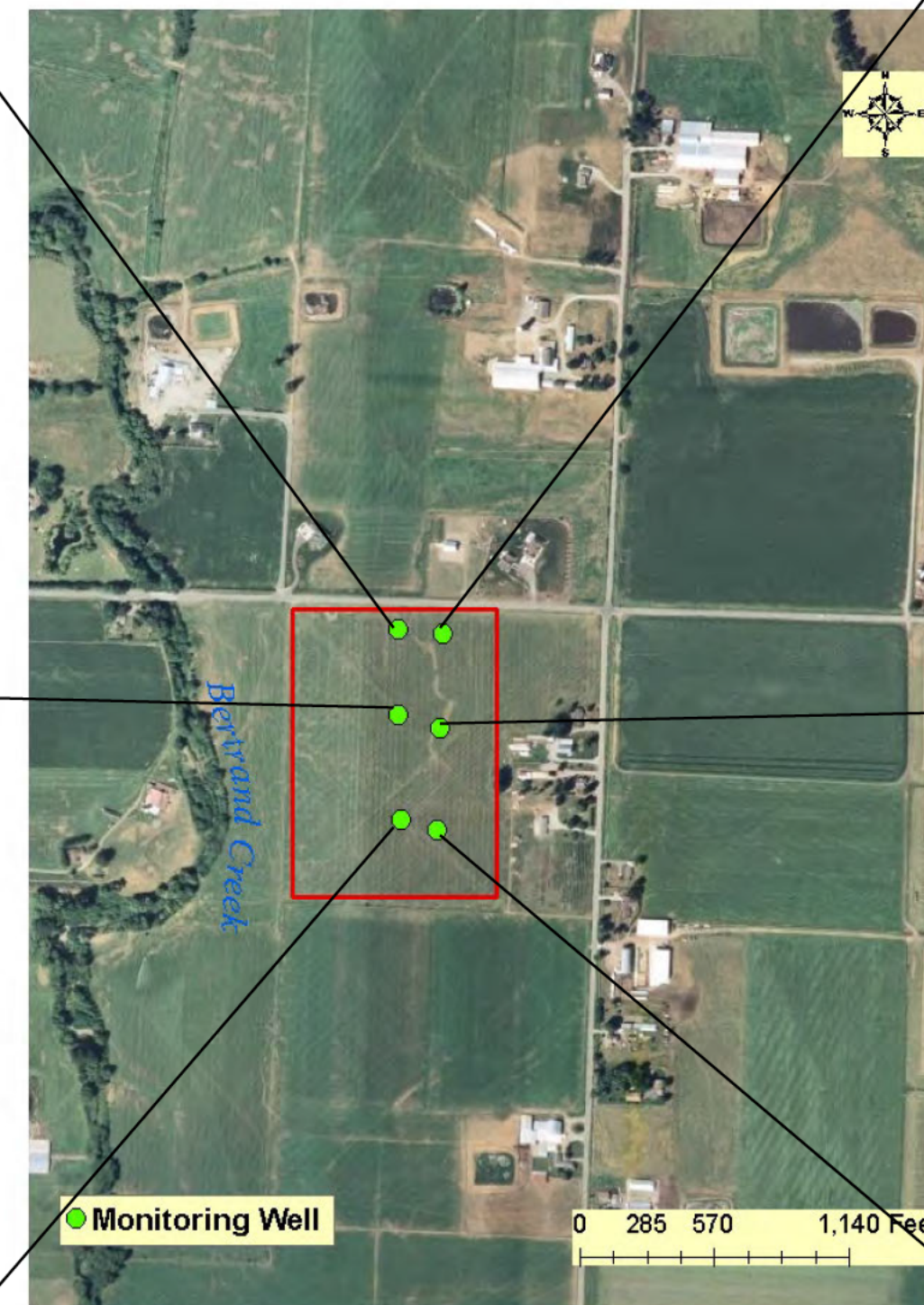
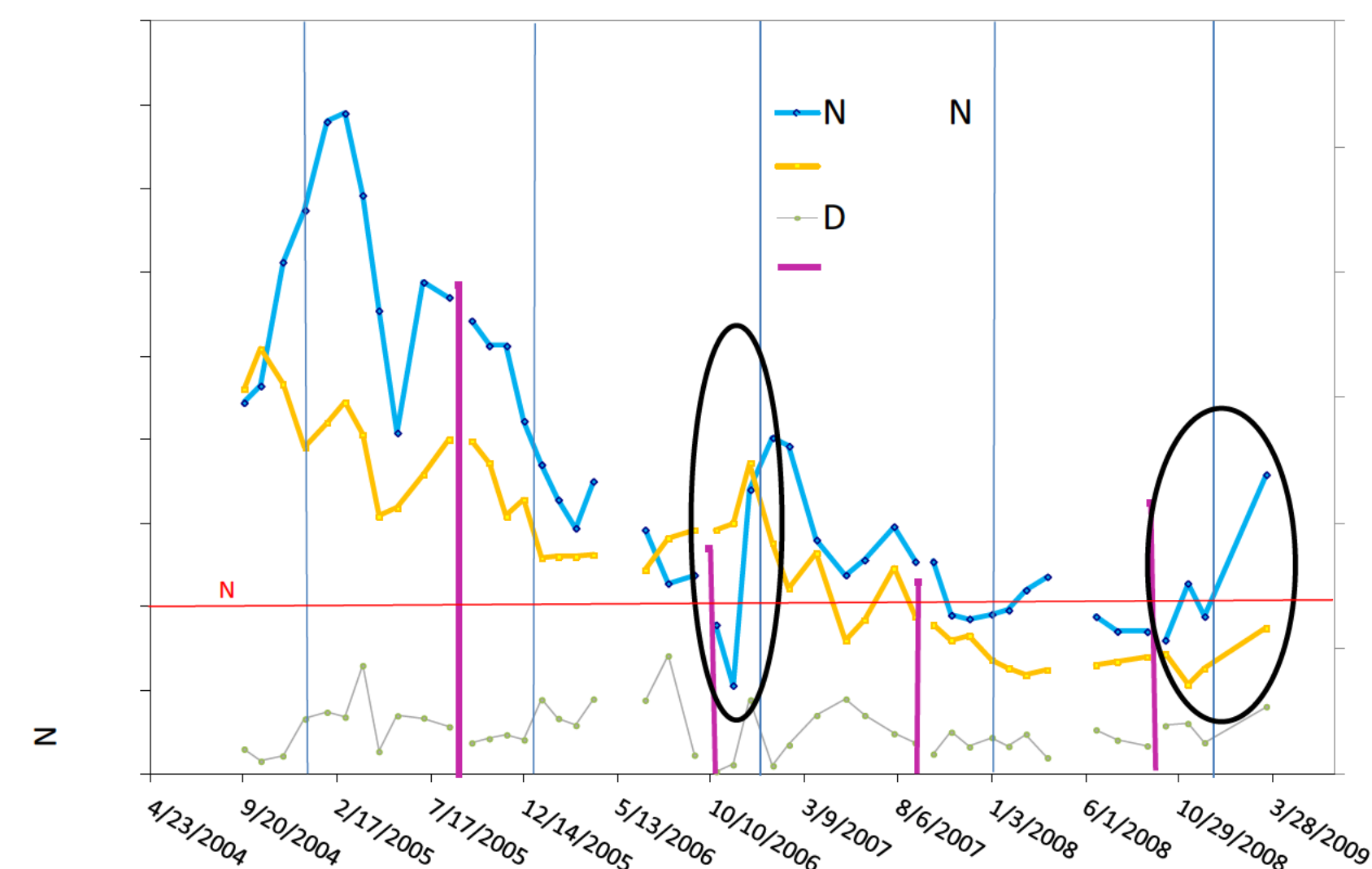
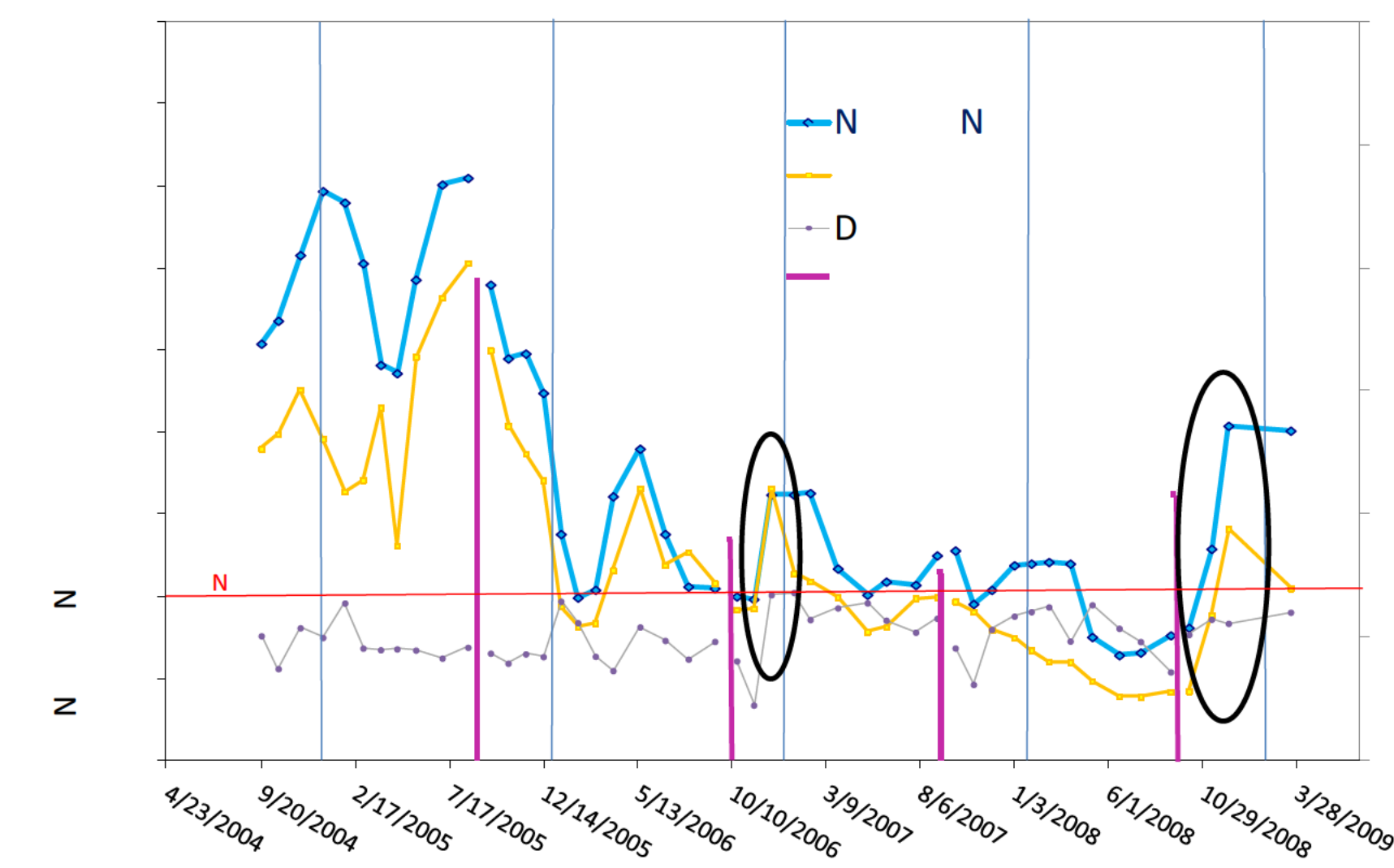
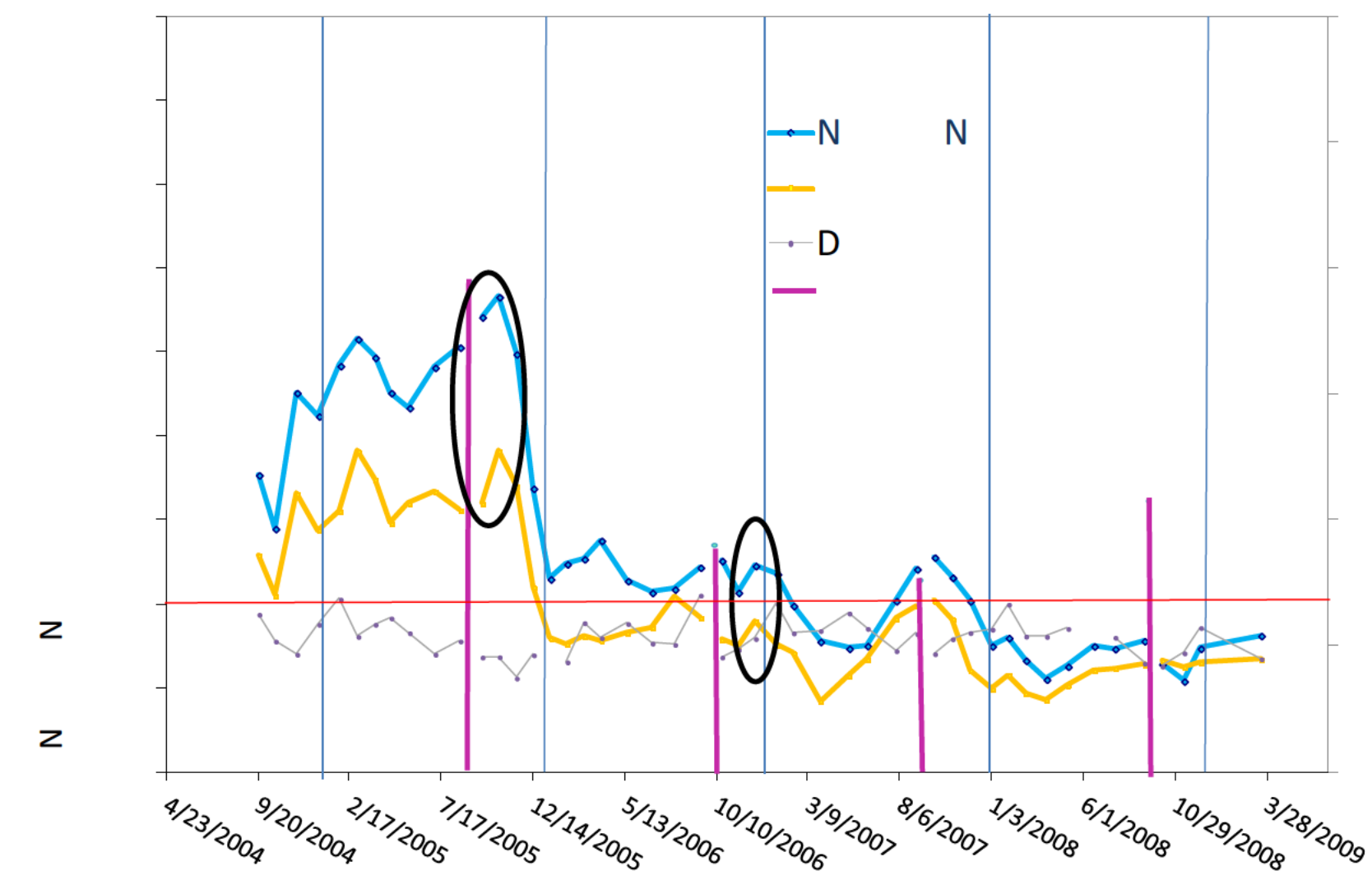


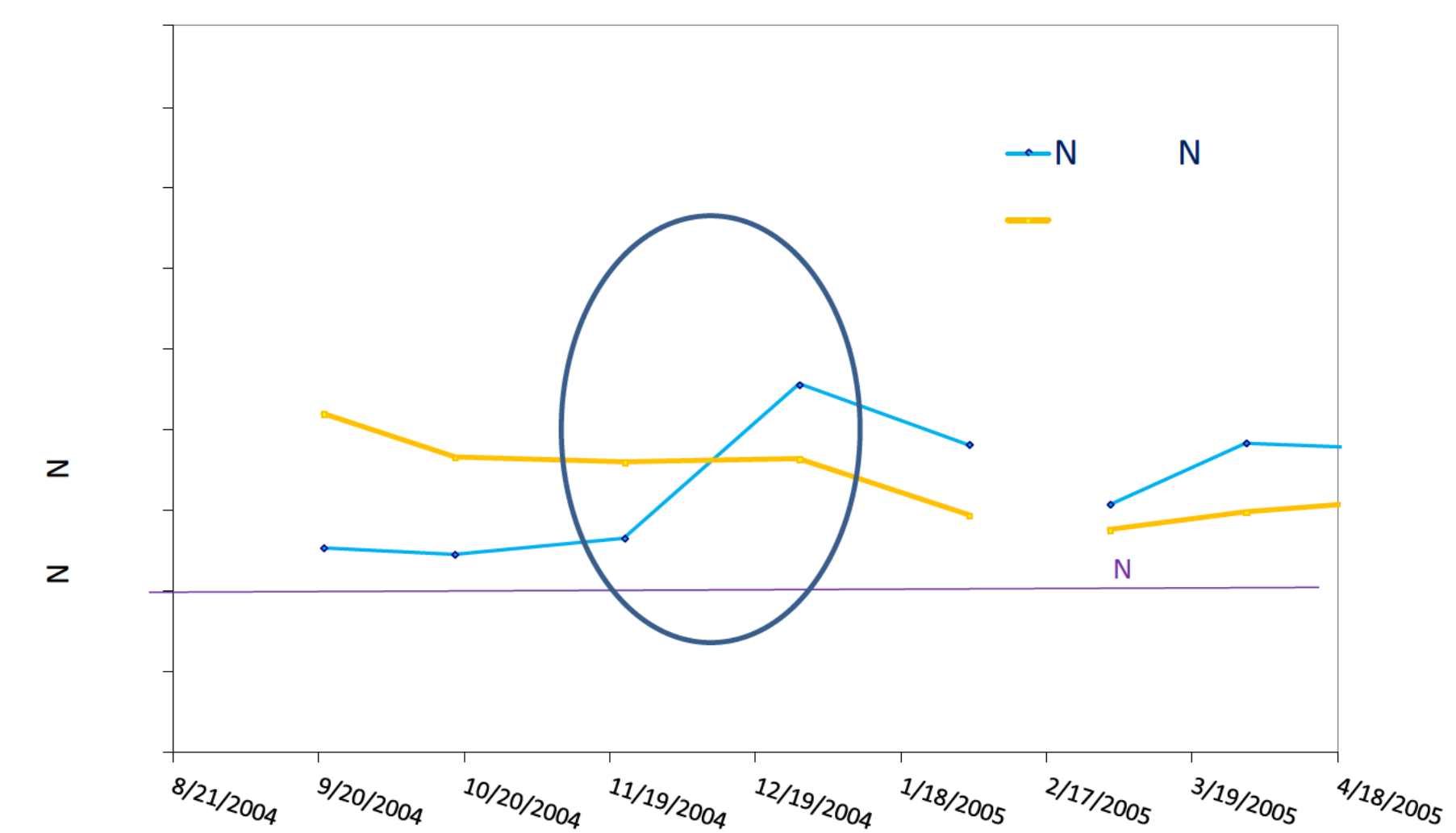
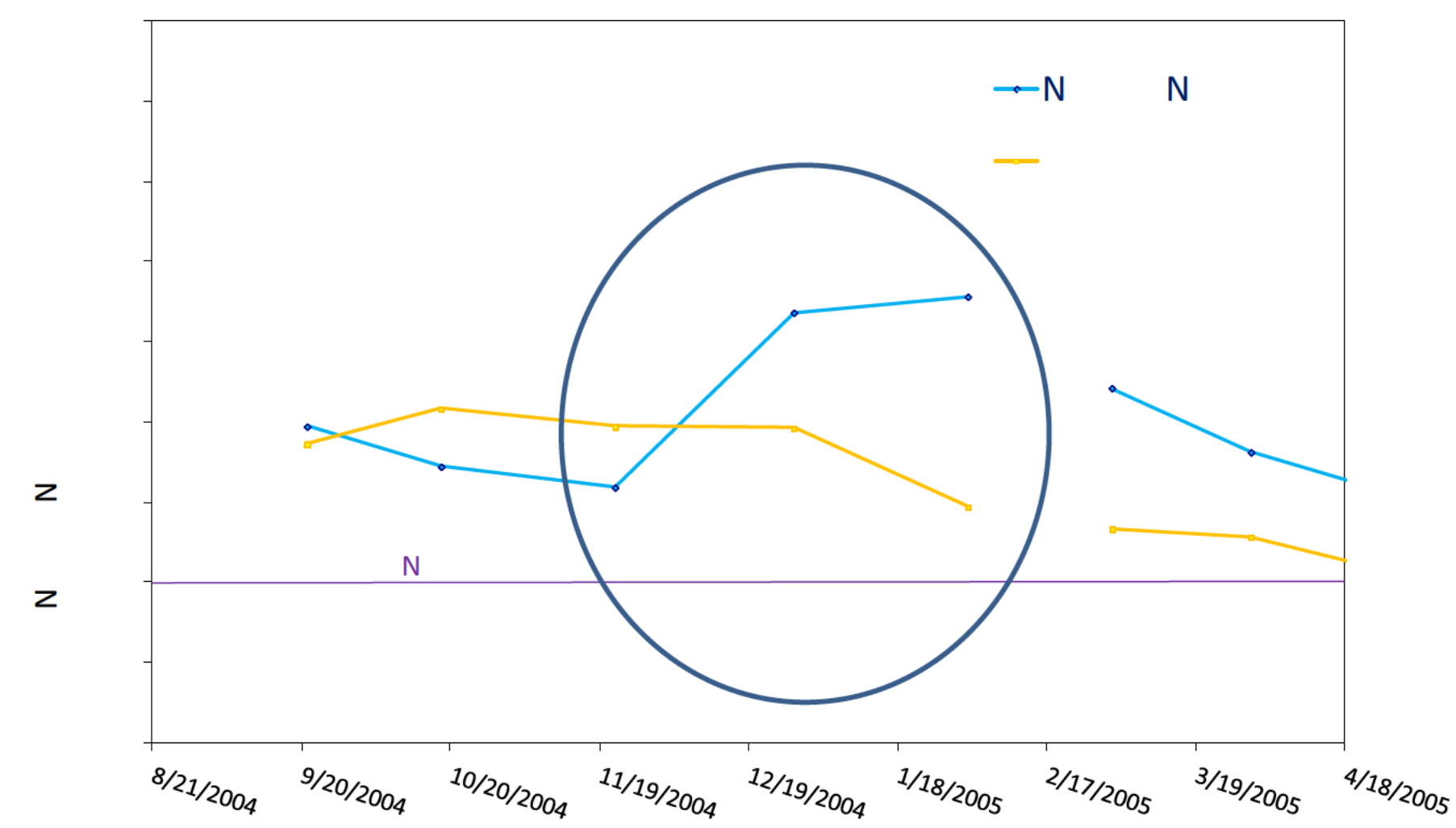
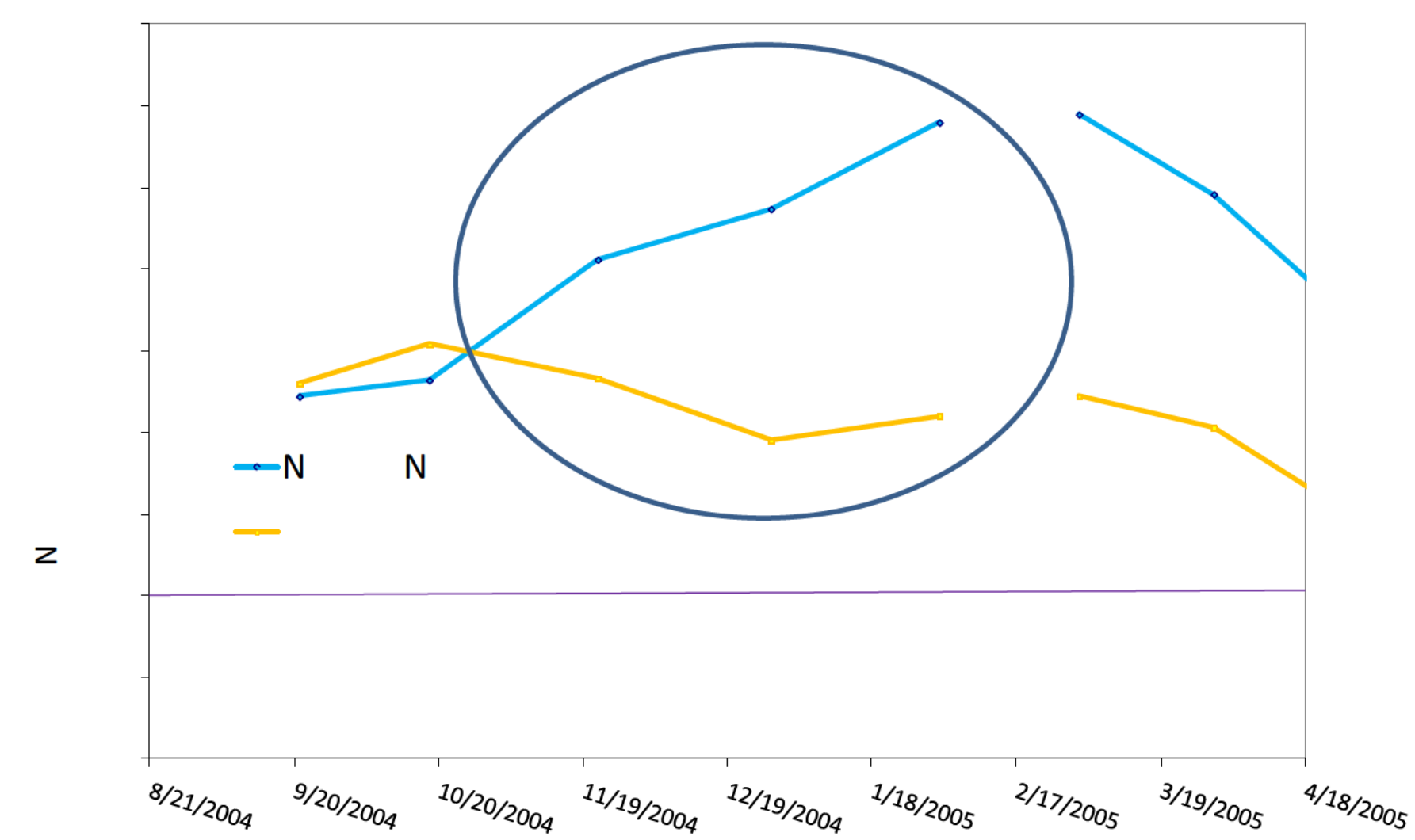
Figure 53. Monthly mean shallow nitrate-N concentrations and annual estimated excess nitrogen.



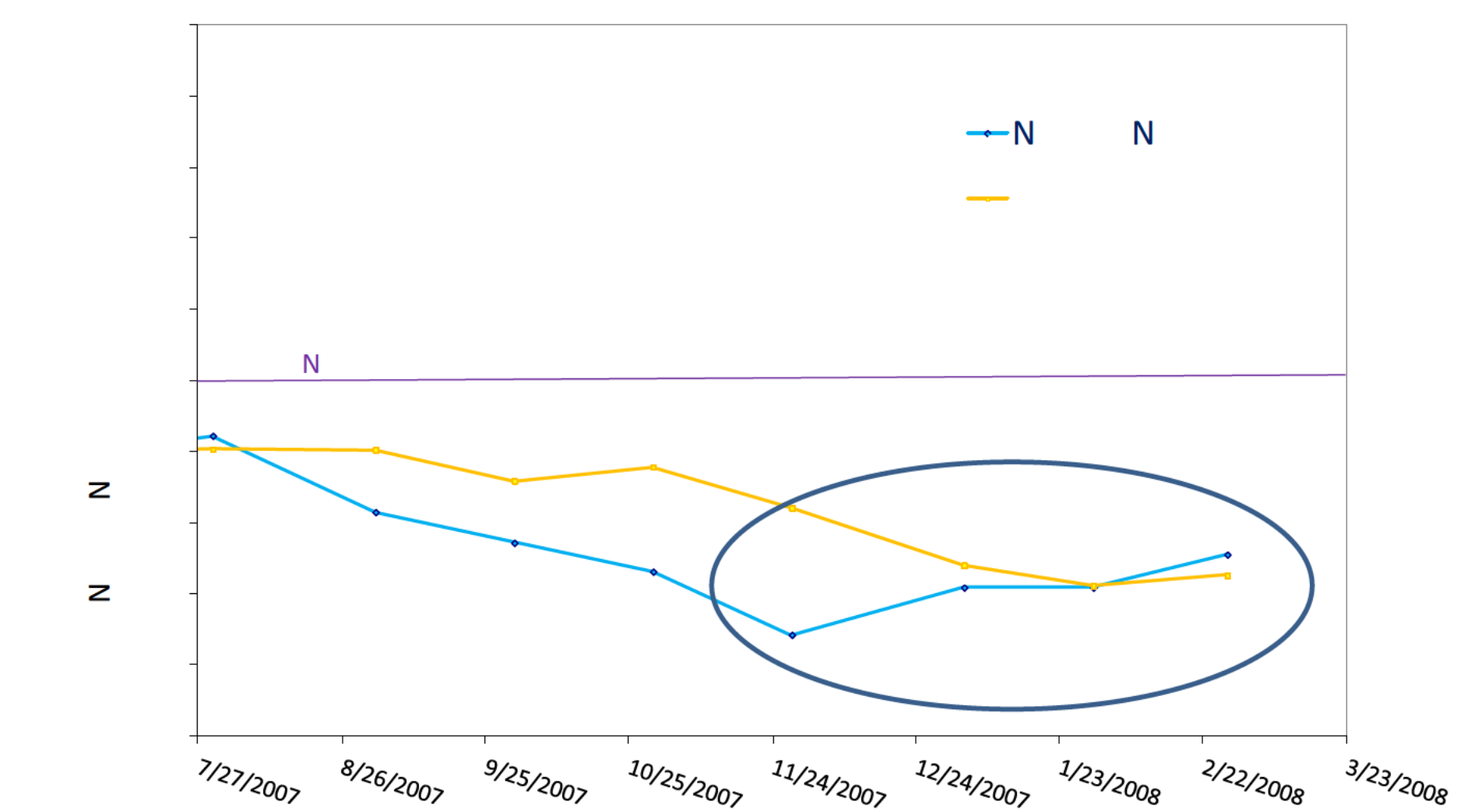
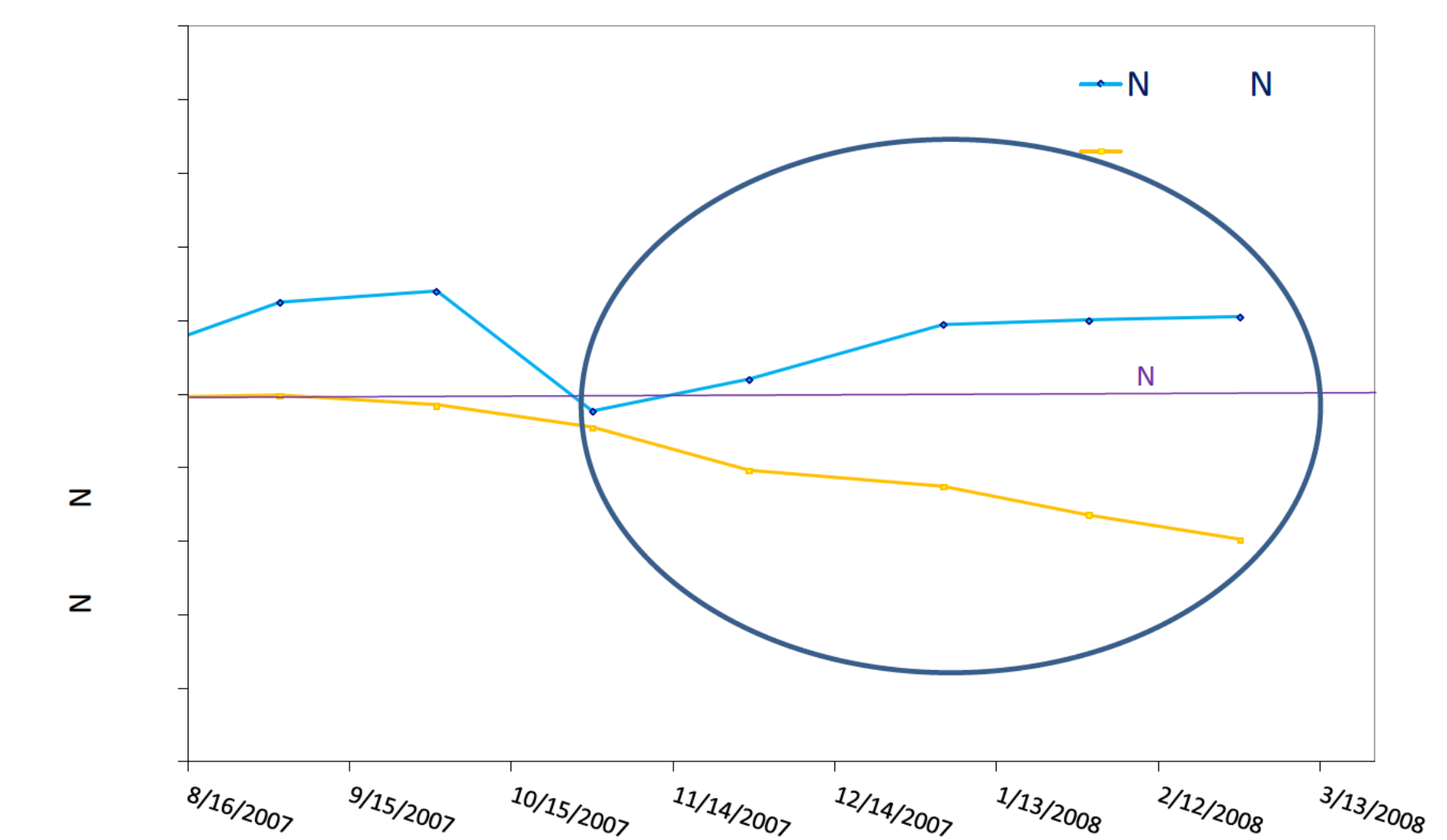
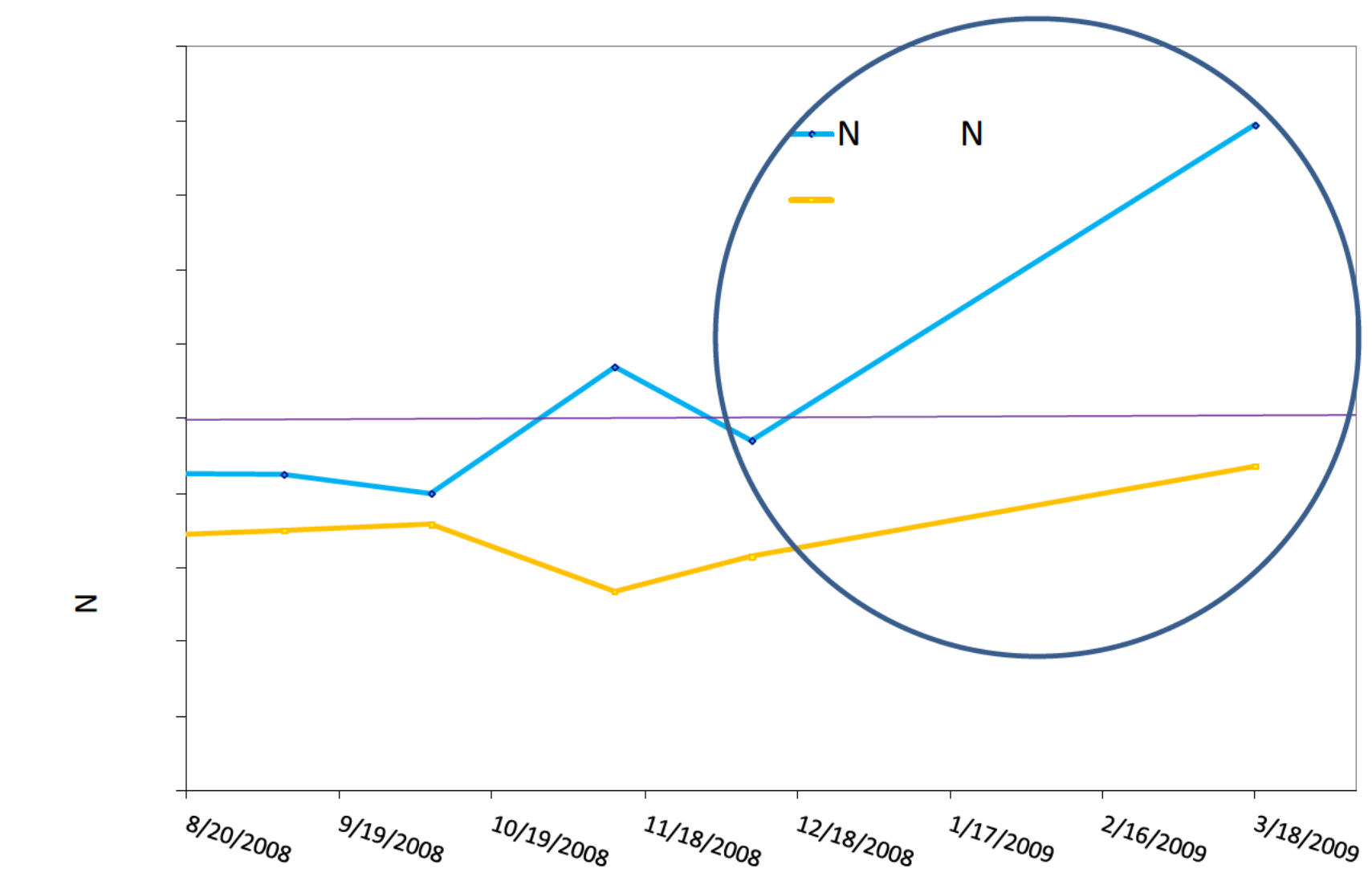
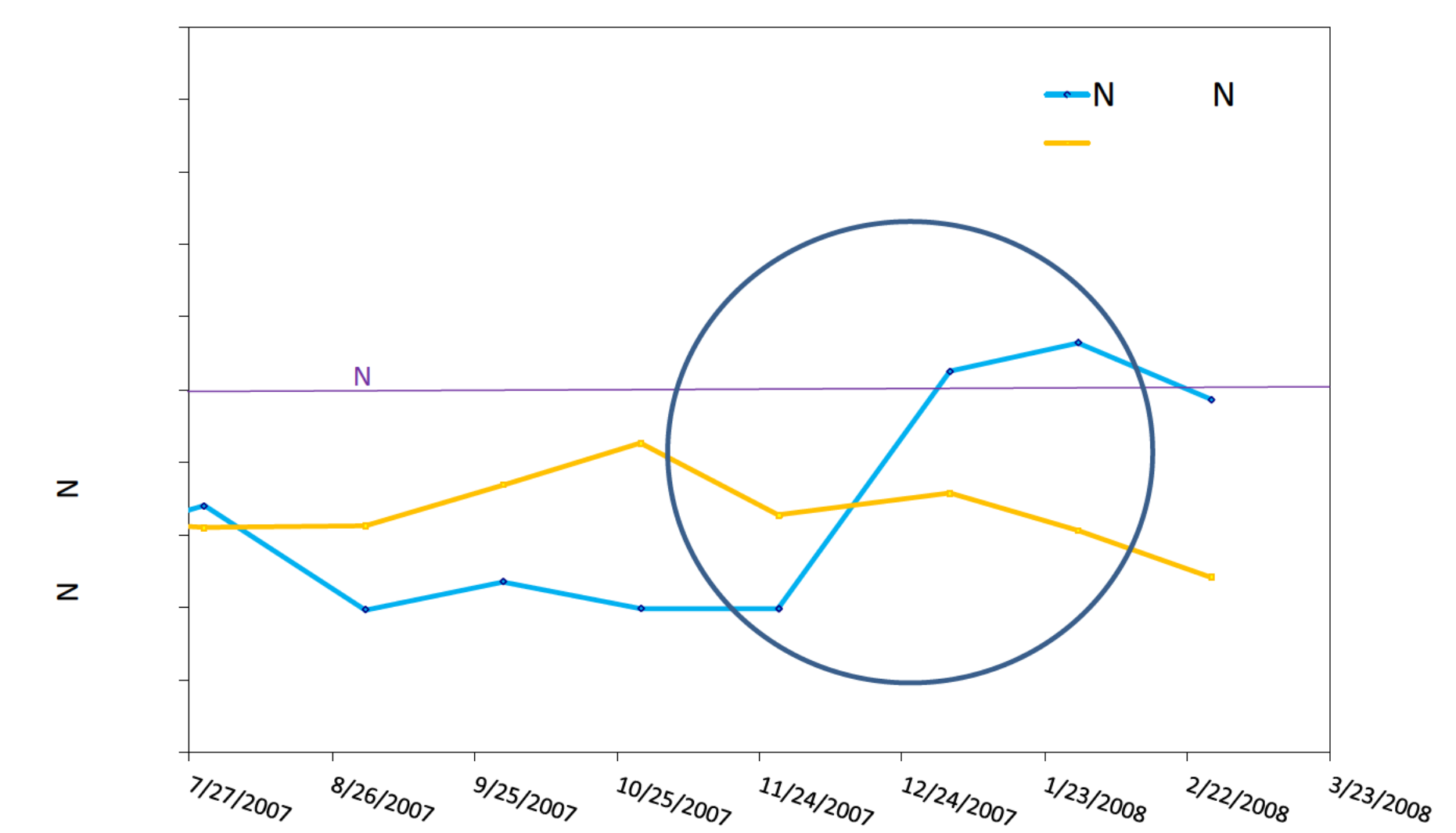
Page 7 Nitrate-N concentration and dissolved oxygen concentration at individual monitoring wells in mg/L and pumping manure application to agricultural fields show times when spring manure application was followed by elevated groundwater nitrate concentrations



Winter 2004 to 2005



Winter 2007 to 2008



Page 9 Nitrate and chloride concentrations during the winters of 2004-2005 and 2007-2008 show groundwater cycles and indicate times when nitrate increases and chloride does not